United States Department of Agriculture

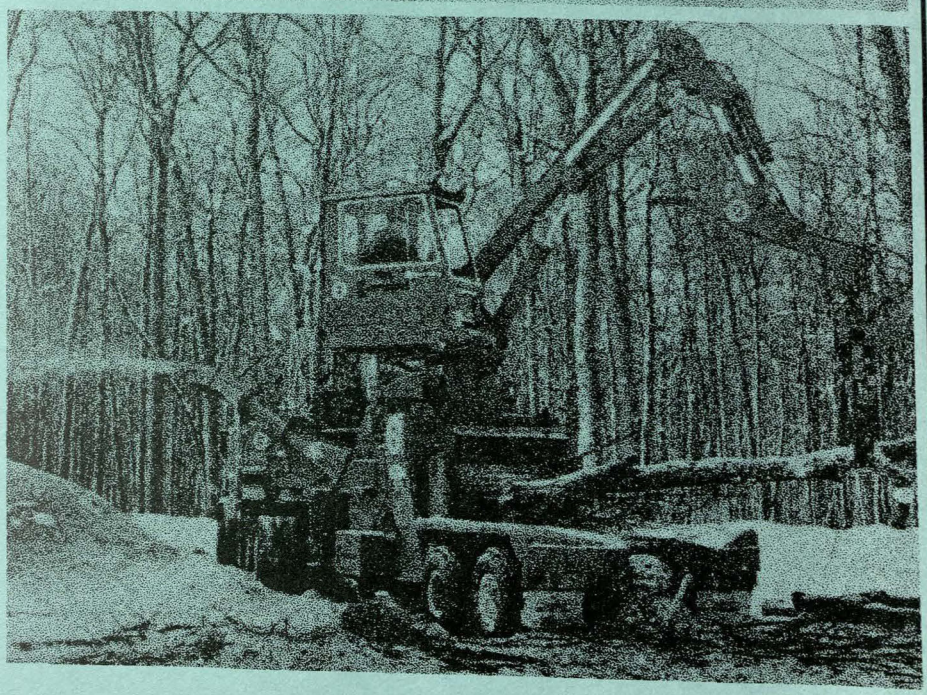
Forest Service

North Central Forest Experiment Station

Research Paper **NC-221**

A Program and Documentation for **Simulation of Grapple Skidders and a Whole-Tree Chipper**

Sharon A. Winsauer



North Central Forest Experiment Station
Forest Service—U.S. Department of Agriculture
1992 Folwell Avenue
St. Paul, Minnesota 55108
Manuscript approved for publication April 12, 1982
1982

CONTENTS

	Page
The equipmant studied	1
Model objectives	1
Simulation language—GPSS	1
Model assumption	1
Model description	3
Data input	3
Data required by model	7
Simulation output	7
Known differences between systems	10
Conclusions	10
Literature cited	10
Appendix A—Variable lists and definitions	17
Appendix B—Program listing	19
Appendix C—Complete flow charts	36

A PROGRAM AND DOCUMENTATION FOR SIMULATION OF GRAPPLE SKIDDERS AND A WHOLE-TREE CHIPPER

Sharon A. Winsauer, *Computer Specialist,*
Houghton, Michigan

Computer simulation of forest harvesting systems is an efficient tool for resource management. The purpose of this paper is to document a computer model of a skidder-chipper system. The model was developed to provide a detailed study of the interaction between the skidders and the chipper. It allows the user to determine cost and productivity, machine efficiency, and causes of delays for various system configurations. Complete variable lists, program listings, and flow charts are included in Appendices A, B, and C.

THE EQUIPMENT STUDIED

The equipment modeled are grapple-type skidders and a whole-tree chipper with a self-loading grapple (figs. 1 and 2). The simulation assumes that the felling was done far enough in advance of the skidders so there is no conflict between fellers and the skidders and that wood to be skidded is always available.

MODEL OBJECTIVES

The primary objective of this model is a detailed look at productivity and efficiency of a given skidder-chipper combination (size of chipper, number and size of skidders). The trees to be skidded are assumed to be bunches left by earlier felling. The number of trees in each bunch can be obtained from the output of a feller/buncher simulation (Winsauer 1980, Winsauer and Bradley [In prep.]).

For input, the model requires data on the operating characteristics of the skidders and the chipper, the number of trees in each bunch, and stand conditions such as diameters of trees cut and skid distances.

After simulating the harvest of a stand, the model reports productivity figures for both types of equipment such as bunches, trees and volume skidded, trees and volumes chipped, and number of vans filled. Additional output gives the productive and delay times and causes for each type of equipment, etc.

SIMULATION LANGUAGE—GPSS

The simulation is written in General Purpose Simulation System (GPSS) with output subroutines written in FORTRAN. GPSS is a discrete event simulation language developed by IBM (Schriber 1974). The user constructs a block diagram by arranging the discrete events of a system in their logical structure. The block diagram is made up from a group of specific GPSS block types. These blocks then become the GPSS program. A basic understanding of the GPSS language allows the user to accurately interpret or modify the simulation.

Most versions of GPSS have a standard output format that contains all the data in a very concise form. The FORTRAN subroutines are used to present the output values of most interest in an organized, labeled form.

MODEL ASSUMPTIONS

The basic time unit used in the model is a centi minute; i.e., 1/100 of a minute. The equipment works one shift a day for the number of days chosen by the user. All volume measures are in 1/100 cubic foot of solid wood.

It is assumed that the trees in the plot have already been felled and to some degree bunched by

Figure 1.—*Grapple type skidder.*

Figure 2.—*Whole-tree chipper.*

either man or machine. To obtain simulation results involving the interaction of feller and skidders, it would be necessary to combine this model with a felling model.

The following assumptions are made about the system:

1. The equipment works one shift a day, then is turned off for the remainder of 24 hours.
2. Production reports and statistics are produced at the end of each 24-hour day, so they include any overtime that may have been worked on a shift.
3. Two 15-minute coffee breaks and one 30-minute lunch break are scheduled each shift. The chipper can take a break only when the van is full. The skidders can break when they reach the landing if, and only if, the chipper is on break.
4. Each skidder travels from landing to the woods along a "skid road." It then travels through the woods to a bunch, grapples it, and hauls it to a collection point where it can drop trees and rebunch if desired. It also has the option of returning for a second bunch before hauling to the landing. The load is skidded back to the landing along the skid road.
5. There is limited space at the landing for wood, so the skidder may have to wait for room before dropping the load.
6. The skidders can quit for the day only if the chipper has quit. The skidder always drops the bunch before quitting.
7. There is room for one van at the chipper. When the van is full, the chipper must wait for it to be moved out and another van moved in.
8. A van is considered full when the volume in the van—after the last load added—is equal to or greater than the volume indicated in X$VANCY. Since the model uses hundredths of cubic feet, this value should also be in hundredths. The van capacity must also be measured in the same type of volume used in the models; i.e., solid wood.
9. The chipper can take a break or quit for the day only after it has finished filling a van.
10. One specific chipper delay has been incorporated into the model. For a certain percent of the chip loads, X$PDELY, the chipper is delayed while the log is bucked to fit into the chipper opening. By setting X$PDELY to zero, the user can eliminate this delay source.
11. To avoid carrying excessive data through the model, the skidders and chippers draw d.b.h. values for the trees from separate, but identical, distribution functions. In this way there is a 1 to 1 correspondence between trees skidded and trees chipped. This required function DBH and DIAM to be identical except for the random number generator; one uses RN4, the other, RN5. These random number generators must be given identical seed values.

MODEL DESCRIPTION

The model consists of three GPSS segments:
1. TIMER SEGMENT
2. SKIDDER SEGMENT
3. CHIPPER SEGMENT

and three FORTRAN subroutines for formatted (easily read) output.

The TIMER SEGMENT (fig. 3) controls the daily schedule, keeps track of the days worked, and sends information to the subroutines to produce the formatted output. The TIMER signals the start of the day, the rest breaks and lunch (two 15-minute breaks a day and 1/2-hour lunch are assumed), and the end of the workday. The TIMER then completes the 24-hour day and produces an output report of the previous day's operation and production. Output is produced at the end of 24 hours, not at the end of the shift, to include the time needed to finish filling the last van before quitting for the day. If the required number of days have been simulated, the model shuts off. Otherwise, the start of another workday is signaled, and the process continues.

The SKIDDER SEGMENT (fig. 4) models one or more identical grapple-type skidders. Each skidder retrieves bunches of previously felled trees and skids them to a landing to be chipped.

The CHIPPER SEGMENT (fig. 5) models a whole-tree chipper with self-loading grapple. The chipper landing is located in or near the woods so that chip vans can be brought to the chipper.

DATA INPUT

GPSS accepts input data in several forms (table 1). For additional information on data types and card formats, see a GPSS Programming Manual (Schriber 1974).

Most of the data required in the main program are expected in the form of VARIABLES. VARIABLES can be defined in terms of the input data available at the end of the deck allowing the user flexibility in data form while avoiding card shuffling in the main program. For example, a skidding time

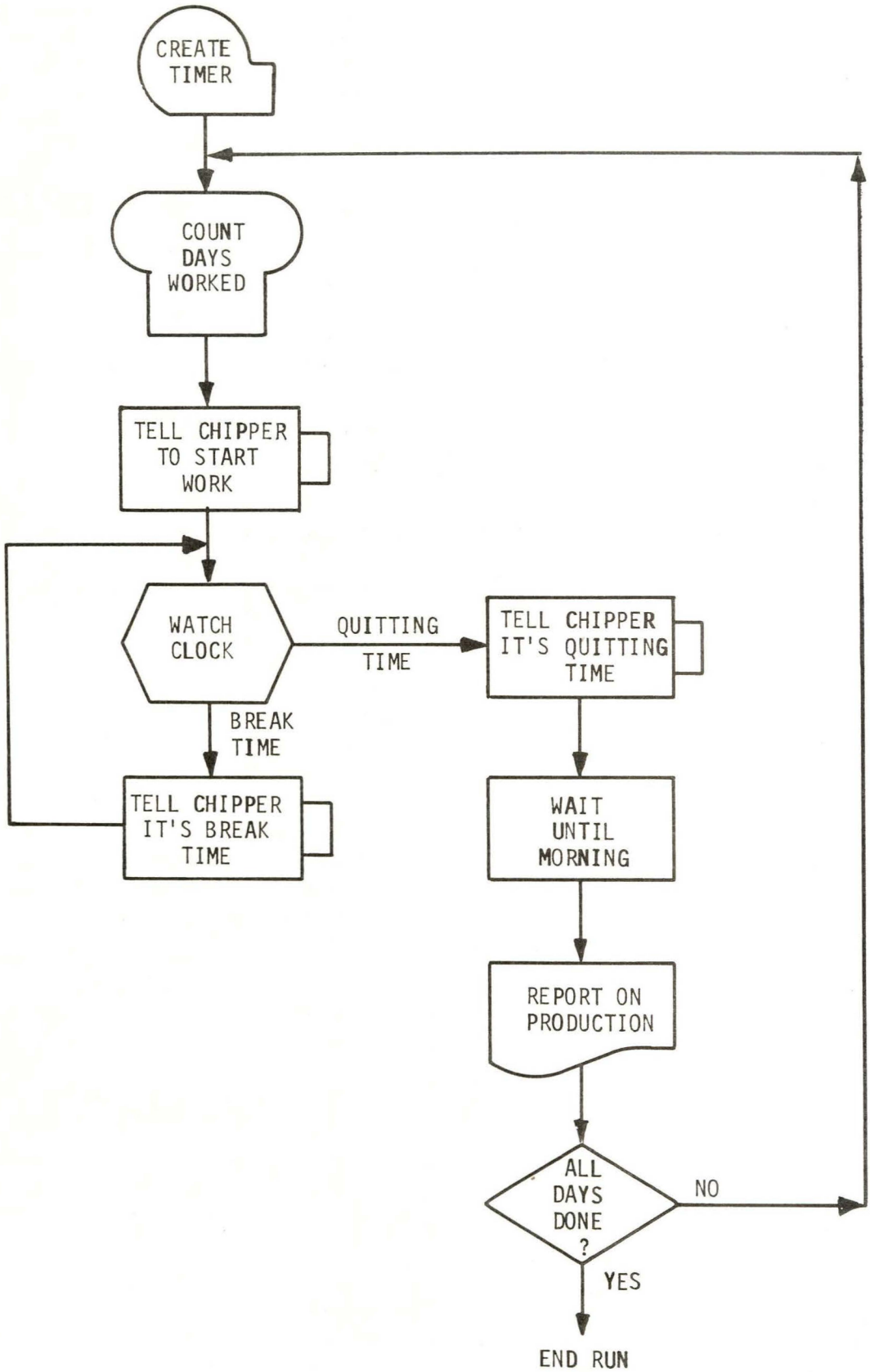


Figure 3.—*Timer segment--overview.*

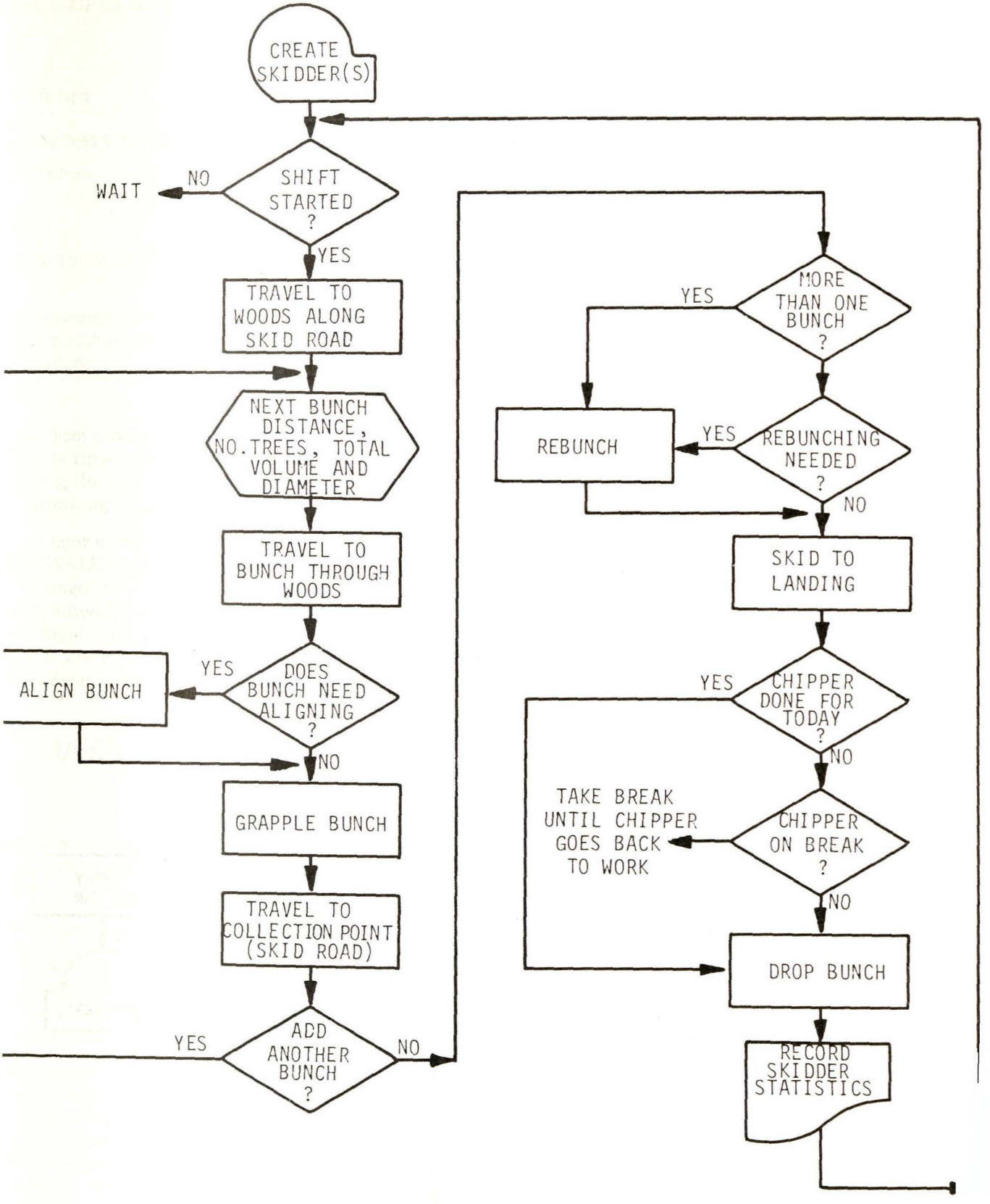


Figure 4.—*Skidder segment--overview.*

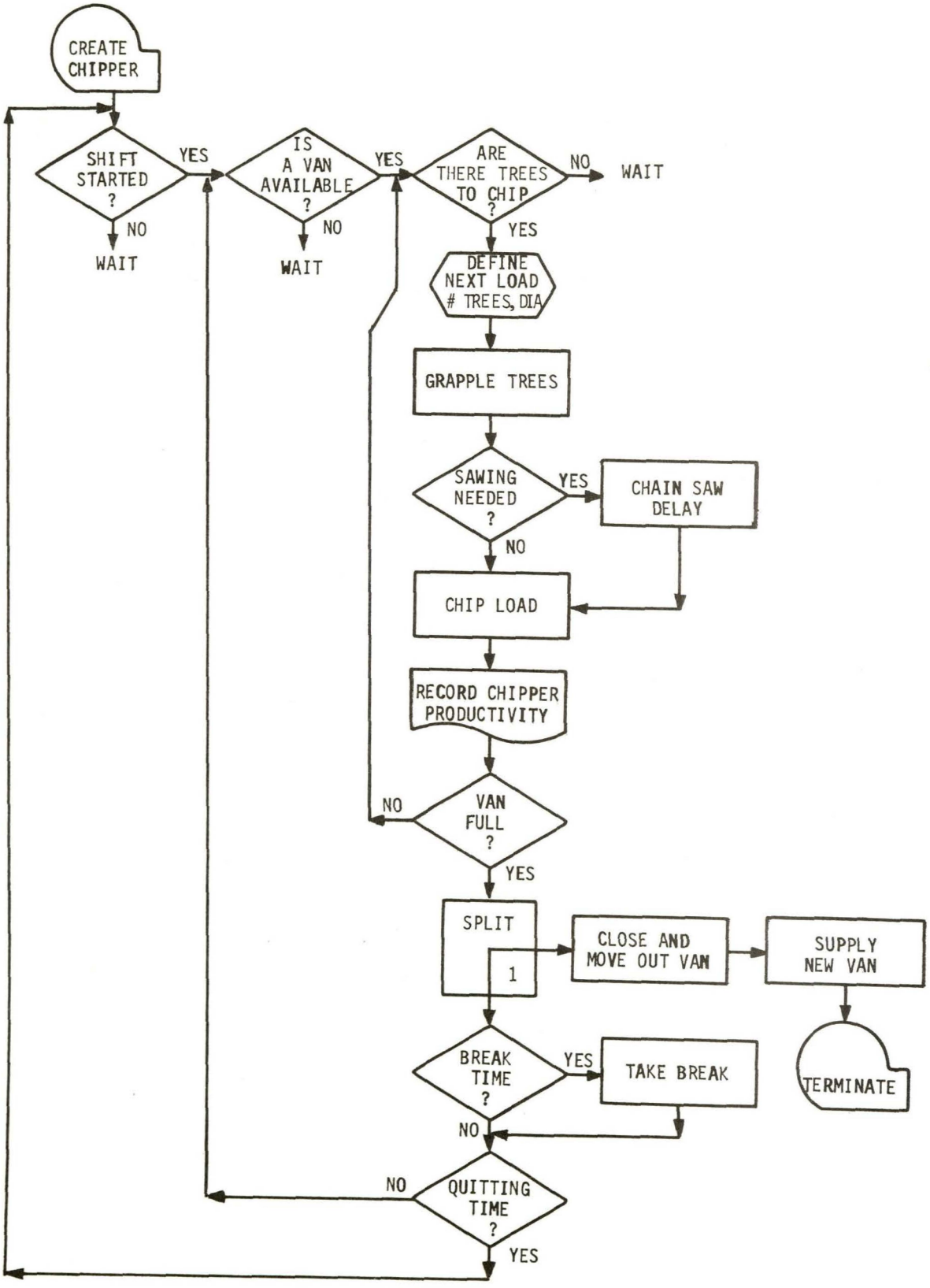


Figure 5.—*Chipper segment--overview.*

Table 1.—*GPSS data input forms*

Input data type	Input form in GPSS	Example
Simple averages or constants	Initialized SAVEVALUES	Average d.b.h. = 6 inches
Range of values	Initialized SAVEVALUES for mean and one-half width of interval	Shear time = 0.10 to 0.14 minutes = 0.12 ± 0.02 minutes
Equations	VARIABLES	Volume = 0.13 d.b.h.^{2}–0.28
Frequency distributions	FUNCTIONS	D.b.h. (inches) 4 | 5 | 6 | 7 | 8 Percent trees 23 | 25 | 30 | 15 | 5
Mean and variance for a standard distribution such as normal, Poisson exponential, etc.	SAVEVALUES and FUNCTIONS for the distribution	Wait time is normally distributed with Mean = 10 Variance = 9

change from a constant (SAVEVALUE) to the product of rate times distance is accomplished by simply redefining the skid time variable and supplying the appropriate input cards.

The major exception to this convention is the use of SAVEVALUES (constants) for the summary values (average stand d.b.h., average tree height, etc.) that are entered simply for use in output tables. The actual input data cards follow the variable definitions and are supplied as FUNCTIONS or SAVEVALUES depending upon the VARIABLE definition.

DATA REQUIRED BY MODEL

Input data describing the equipment and harvesting operation must be supplied to run the simulation.

There are four types of data to be supplied:

1. Stand data (table 2)
2. Machine data for skidders (table 3)
3. Machine data for chipper (table 4)
4. Simulation run control (table 5).

The sample output presented in this paper results from a case study using the data in tables 2-5 as input. These data were gathered from time studies carried out during Forest Service projects and are used to illustrate the model and its use. Bunch size and location data were taken from a simulation run of a tracked type feller/buncher (Winsauer 1980).

The data in the tables are empirical, so they represent the operating characteristics of this machine under given stand conditions. Different harvest conditions will require new input data.

SIMULATION OUTPUT

The simulation run produces three pages of formatted output for each day of the run (figs. 6, 7, and 8). These present a summary of the stand data and cumulative productivity reports. Additional output is produced at the end of the run by the GPSS processor. This output supplies complete run details.

The first page of standard output (fig. 9) presents a simulation "map" listing all the blocks in the model and the number of transactions that have moved through each block. This is primarily of value while debugging the model. The listing of the QUEUE statistics provides detailed information on how time is spent and delays for each type of equipment. The SAVEVALUE list contains all the totals necessary to calculate productivity if the FORTRAN subroutines cannot be used.

Example:
CPHR = 4,230 = chipper hours x 100
CPTRE = 14,218 = trees chipped
CPVNS = 52 = vans filled
52/42.30 = 1.23 vans/hour
14,218/42.30 = 336 trees/hour
14,218/52 = 273.4 trees/van

The tables (figs. 10-11) provide additional details of the machine performance.

Table 2.—*Stand data*

Data required	Case study	Form required by program	Name
Average stand diameter	5.5 in d.b.h.	SAVEVALUE	X$AVDBH
Average stand volume	3,450 cu ft/acre	SAVEVALUE	X$AVVOL
Average tree height	43 ft	SAVEVALUE	X$AVHGT
Average trees/acre	844	SAVEVALUE	X$TRPAC
Density of wood	55 lb/cu ft	SAVEVALUE	X$LBCFT
Energy equivalent-fuel	150,000 BTU/gal	SAVEVALUE	X$FBTU
Energy equivalent-wood	8,000,000 BTU/ton	SAVEVALUE	X$WBTU
Skid distance-road/track	300 ft	VARIABLE	V$RDIST
Skid distance-woods	Distribution[1]	VARIABLE	V$WDIST

Distance (ft)	0-5	5-10	10-15	15-20	20-25	25-30	30-35
Percent time	23	12	7	11	10	9	5

35-40	40-45	45-50	50-55	55-60	60-100
2	3	4	2	2	10

Actual tree diameter	Diameter distribution:	FUNCTION	FN$DBH FN$DIAM[2]

D.b.h (in.)	3	4	5	6	7	8	9
Percent trees	5	23	30	24	14	3	1

Tree volume	Volume (cu ft) $= -0.283 + 0.0031$ (d.b.h.^{2}) tree height $= 0.283 + 0.133$ (d.b.h.^{2}) assuming tree height = 43 ft	VARIABLE	V$TVOL
Type of feller/buncher	Tracked	SAVEVALUE	X$FBTYP
Number of feller/bunchers	1	SAVEVALUE	X$NUMFB
Feller/buncher fuel consumption	3.3 gal/ton	SAVEVALUE	X$FBGPT
Number of trees per bunch left by feller/buncher	Distribution-trees per bunch[1]	VARIABLE	V$NTBUN

Trees/bunch	2	3	4	5	6	7	8	9	10
Percent bunches	0.4	2.1	3.5	3	6	5	4	6	5

11	12	13	14	15	16	17	18	19
4	6	7	6	3	5	4	3	3

20	21	22	23	24	25
4	4	3	4	4	6

[1]Distributions taken from simulation run of tracked feller/buncher (Winsauer 1980)
[2]FN$DBH and FN$DIAM are identical distribution functions used by skidders and chipper, respectively.

Table 3.—*Skidder data*

Data required	Case study	Form required by program	Name
Number of skidders	1	SAVEVALUE	X$NUMSK
Maximum gapple load (total sum of diameters)	150 inches	SAVEVALUE	X$MXSKD
Fuel consumption	4 gal/hr	SAVEVALUE	X$SKGPH
Travel time along skid road/track-based on distance	Distance/speed Road speed = 352 ft/min = 4 mph	VARIABLE	V$RTRAV
Travel time in woods-based on distance	Distance/woods speed Woods speed = ⅔ road speed	VARIABLE	V$WTRAV
Grapple time/bunch	Mean = 0.65 min Std. dev. = .20 min	VARIABLE	V$GRAPL
Time to align bunch, if needed	Mean = .50 min Std. dev. = .30 min	VARIABLE	V$ALIGN
Percent of bunches needing alignment before grappling	1 percent	SAVEVALUE	X$ALIGN
Drop time per load	Mean = .30 min Std. dev. = .15 min	VARIABLE	V$DROP
Rebunch time/load	Mean = .50 min Std. dev. = .25 min	VARIABLE	V$REBUN
Percent of single bunches needing to be rebunched before hauling	15 percent	SAVEVALUE	X$REBUN
Conditions under which the skidder will add another bunch before skidding to landing	Skid grapple load less than one/half its capacity	Boolean VARIABLE	BV$ADD

Table 4.—*Chipper and van data*

Data required	Case study	Form required by program	Name
Maximum chipper grapple load	12 trees	SAVEVALUE	X$CMAX
Room at landing	50 tree	SAVEVALUE	X$BUFLM
Chipper fuel consumption	5.7 gal/hr	SAVEVALUE	X$CPGPH
Actual grapple load	Distribution: trees/ grapple load	VARIABLE	V$NGRAP

Number of trees	1	2	3	4	5	6	7	8	9	10
percent of grapple loads	12	19	18	17	15	8	7	3	1	1

Grapple and chip time/load	0.10 min per stem	VARIABLE	V$CHIP
Delay time for sawing	mean = 0.48 min Std. dev. = .09 min	VARIABLE	V$CHSAW
Percent of chip loads needing sawing	5 percent	SAVEVALUE	X$PDELY
Van capacity	1,000 cu ft (solid wood) (approximately 30 tons)	SAVEVALUE	X$VANCY
Time to close van	1 minute	VARIABLE	V$CLSVN
Time to change vans	4 minutes	VARIABLE	V$VNWAT

Table 5.—*Simulation run control*

Data required		Case study	Form required by program
Random number generators	Random number	Use	
	1	GPSS scheduler	RMULT CARD
	2	Generate normal random distributions	
	3	FUNCTIONS for wood distance, trees/ bunch, chipper-grapple load	
	4, 5	Diameter distributions-these should have identical seed values and not be used for any other functions	
Number of days to simulate	5		START CARD
Standard output	Every fifth day		START CARD

It should be noted that all of the output was obtained by random processes in the model. Therefore, the output data are themselves random numbers, only a sample of what could happen. If the model is run again with different random numbers, the results will be different. An average over several days or several runs is the best estimate of an actual system.

KNOWN DIFFERENCES BETWEEN SYSTEMS

The program listed in the Appendix is operational on a UNIVAC 1110 under an implementation of GPSS called GPSS-X8, obtained through Use Program Library Interchange (UPLI). It should run under most GPSS processors with only minor changes. The following should be checked for your system.

INITIAL cards—In GPSS-X8 the INITIAL cards appear last in the deck. They should be moved to the head of the deck for most other GPSS processors.

JOB CONTROL cards—These are unique to each computer lab and must be obtained locally.

HELP BLOCKS—In GPSS-X8 HELP BLOCKS (lines 105-152 in the program) are used to pass an array of up to five integer values to a FORTRAN subroutine. Only a one-way transfer is permitted; the subroutine cannot pass arguments back to GPSS.

Some versions of GPSS do not allow HELP BLOCKS. In this case the program can be run without lines 105 to 152 and the data obtained instead from the standard output. If some form of HELP BLOCKS are allowed, the HELP BLOCKS formats and the subroutines may have to be changed. See the GPSS manual for your computer installation.

CONCLUSIONS

The simulation model provides an in-depth look at the operation of the system. This makes it possible to determine the effect on productivity and type of delays caused by changes in the system (table 6) or the stand. It can also be used in conjunction with other models to determine the cost and feasibility of a complete harvesting operation.

Some knowledge of GPSS allows the user to modify the model to meet his exact needs, making it even more useful and realistic.

LITERATURE CITED

Schriber, T. J. Simulation using GPSS. New York: John Wiley & Sons; 1974. 533 p.

Winsauer, Sharon A. A program and documentation for simulation of a tracked feller/buncher. Res. Pap. NC-192. St. Paul, MN: U.S. Department of Agriculture, Forest Service, North Central Forest Experiment Station; 1980. 26 p.

Winsauer, Sharon A.; Bradley, Dennis P. A program and documentation for simulation of a rubber-tired feller/buncher. Res. Pap. NC-212. St. Paul, MN: U.S. Department of Agriculture, Forest Service, North Central Forest Experiment Station; 1982. 34 p.

```
                                SAWLOG  SORTING  SIMULATOR

                                    DEVELOPED  BY  THE
                          NORTH CENTRAL FOREST  EXPERIMENT  STATION
                        FOREST  SERVICE,  U. S.  DEPT.  OF  AGRICULTURE
      FOREST  PRODUCTS  MARKETING  AND  UTILIZATION  PROJECT,  DULUTH,  MINNESOTA
                                        AND  THE
                    FOREST  ENGINEERING  LABORATORY, HOUGHTON,  MICHIGAN
                                        AUTHORS
                                  DENNIS P. BRADLEY, ECONOMIST
                                SHARON A. WINSAUER, PROGRAMMER

I.  STAND CHARACTERISTICS.
     3450.00 CUFT., AVERAGE VOLUME PER ACRE.
        5.50 INCHES, AVERAGE DBH.
       43.00 FEET, AVERAGE TREE HEIGHT.
      844.00 AVERAGE NUMBER OF TREES PER ACRE.
        7.18 FEET, AVERAGE TREE SPACING.

II.  SYSTEM CHARACTERISTICS AS SPECIFIED BY THE ANALYST.
  A.  FELLER-BUNCHERS.                    1  MACHINE(S)     TRACKED TYPE

  B.  SKIDDERS.                       1  MACHINE(S)     RUBBER-TIRED GRAPPLE SKIDDER(S).

      MAXIMUM SKID BUNCH HAS TOTAL SUM OF DIAMETER  150.00 INCHES


  C.  CHIPPER-LOADER.
      THE LOADER CAN TAKE A LOAD OF   12.TREES
     ENERGY BALANCE
             .33 GAL/TON - FELLER BUNCHER
             .10 GAL/TON - SKIDDER
             .14 GAL/TON - CHIPPER
             .57 TOTAL GAL/TON.
    85719.38 BTU/TON USED AS FUEL
  8000000.00 BTU/TON HARVESTED FROM WOOD

       93.33     ENERGY BENEFIT RATIO.
```

Figure 6.—*Simulation output--system and stand characteristics.*

```
                    S K I D D I N G   P R O D U C T I O N   A N D   C O S T   S U M M A R Y

**********************************************************************************************
I.     A.    42.48      HOURS WORKED BY SKIDDER(S).
       B.     1         NUMBER OF SKIDDER(S).
II.    A.   589         BUNCHES SKIDDED - ALL MACHINES.
                 1.76      AVERAGE NUMBER OF FELLER-BUNCHER BUNCHES COLLECTED.
                24.20      AVERAGE NUMBER OF TREES PER SKIDDER BUNCH.
       B.14256           TREES SKIDDED - ALL MACHINES.
       C.52449.29        VOLUME SKIDDED - CU.FT. - ALL MACHINES.
       D.  405248        TOTAL DISTANCE SKIDDED.
       E. 1704.60        TOTAL TONS SKIDDED - ALL MACHINES.

III.   A.    13.87      BUNCHES SKIDDED PER MACHINE HOUR.
       B.   335.59      TREES SKIDDED PER MACHINE HOUR.
       C.  1234.68      VOL. SKIDDED PER MACHINE HOUR. - CU.FT.
       D.    40.13      TONS SKIDDED PER MACHINE HOUR.
IV.    A.   344.01      AVERAGE ONE-WAY SKID DISTANCE PER TRIP - FEET.
       B.     4.33      AVERAGE ROUND TRIP TIME IN MINUTES - ALL ACTIVITIES.
                3.58      TIME - LANDING TO WOODS AND RETURN.
                 .30      PRODUCTIVE TIME - LANDING ACTIVITY.
                 .00      NON-PRODUCTIVE TIME-WAITING TO DROP AT CHIPPER.
                 .45      TIME ON BREAKS
V.     A.   169.92      TOTAL GALLONS USED.
                4.00      GALLONS PER HOUR.
                 .10      GALLONS PER TON.
```

Figure 7.—*Simulation output--skidder productivity.*

```
                    C H I P P E R - L O A D E R   P R O D U C T I O N   A N D   C O S T   S U M M A R Y
*****************************************************************************************************
I.     A.    42.30      HOURS WORKED BY CHIPPER-LOADER.

II.    A. 3928          LOADS CHIPPED.
                  3.62      AVERAGE NUMBER OF STEMS PER LOAD.
                 13.32      AVERAGE VOLUME PER LOAD - CU.FT.
       B.   14218       TREES CHIPPED.
       C.52326.13       VOLUME CHIPPED - CU.FT.
       D. 1700.60       TONS CHIPPED.
       E.       52      VANS FILLED.
                 75.54      AVERAGE NUMBER OF LOADS PER VAN.
               1006.27      AVERAGE VOLUME PER VAN - CU.FT.
                 32.70      AVERAGE TONS PER VAN.

III.   A.    92.86       LOADS CHIPPED PER MACHINE HOUR.
       B.   336.12       TREES CHIPPED PER MACHINE HOUR.
       C. 1237.02       VOLUME CHIPPED PER MACHINE HOUR - CU.FT.
       D.    40.20      TONS CHIPPED PER MACHINE HOUR.
       E.     1.23      VANS FILLED PER MACHINE HOUR.

IV.    A.    48.81      AVERAGE CHIPPING TIME PER VAN FILLED - ALL ACTIVITIES - MINUTES.
                 27.70      PRODUCTIVE TIME PER VAN - MINUTES.
                 21.11      NON-PRODUCTIVE TIME PER VAN - DUE TO EXTERNAL EVENTS - MINUTES.
                       10.58     LOADER WAITING FOR WOOD FROM SKIDDERS - MINUTES.
                        3.02     CHIPPER WAITING FOR VANS TO FILL - MINUTES.
                        1.75     BUCKING TIME
                        5.76     BREAK TIME

VI.    A.   241.11      TOTAL GALLONS OF FUEL USED.
                  5.70      GALLONS/HOUR.
                   .14      GALLONS/TON.
```

Figure 8.—*Simulation output--chipper productivity.*

*** GPSS/X8 NORMAL COMPLETION OF SIMULATION RUN ***

RELATIVE CLOCK: 720001 ABSOLUTE CLOCK: 720001

TRANS COUNT:

BLOCK	TRANS, TOTAL
TIMER	0, 1
6	0, 5
11	0, 5
16	0, 5
21	0, 5
26	0, 5
31	0, 5
OUTPT	0, 5
41	0, 589
WOODS	0, 1038
51	0, 14256
56	0, 1038
61	0, 1038
ALIGN	0, 10
71	0, 1038
76	0, 1038
81	0, 422
86	0, 589
91	0, 589
96	0, 15
101	0, 589
106	0, 589
111	0, 589
116	0, 589
121	0, 5
126	0, 3928
131	0, 335
136	0, 14218
141	0, 194
146	0, 3928
151	0, 3928
156	0, 3928
161	0, 52
NOBRK	0, 52
CDONE	0, 52
LNKVN	0, 52
181	0, 52

BLOCK	TRANS, TOTAL
NXDAY	0, 5
7	0, 5
12	0, 5
17	0, 5
22	0, 5
27	0, 5
32	0, 5
SKDDR	0, 1
42	0, 589
47	0, 1038
52	0, 14256
57	0, 1038
62	0, 1038
67	0, 10
72	0, 1038
77	0, 1038
82	0, 422
87	0, 589
92	0, 589
97	0, 15
102	0, 589
107	0, 589
112	0, 589
WAIT	1, 589
NEWLD	0, 3928
127	0, 3928
GRAPE	0, 3928
137	0, 3928
142	0, 194
147	0, 3928
152	0, 3928
157	0, 52
162	0, 10
167	0, 5
172	0, 52
177	0, 52

BLOCK	TRANS, TOTAL
3	0, 5
8	0, 5
13	0, 5
18	0, 5
23	0, 5
28	0, 5
33	0, 5
START	0, 589
43	0, 589
48	0, 1038
53	0, 1038
58	0, 1038
63	0, 1038
68	0, 10
73	0, 1038
78	0, 589
SKLND	0, 589
88	0, 589
LAND	0, 589
SWORK	0, 589
103	0, 589
108	0, 589
113	0, 589
CHIPR	0, 1
123	0, 3928
128	0, 3928
LOAD	0, 14218
138	0, 3928
CHIP	0, 3928
148	0, 3928
153	0, 3928
FULVN	0, 104
163	0, 10
168	0, 5
173	0, 52
178	0, 52

BLOCK	TRANS, TOTAL
4	0, 5
9	0, 5
14	0, 5
19	0, 5
24	0, 5
29	0, 5
34	0, 5
39	0, 589
44	0, 589
NDBH	0, 14256
54	0, 1038
59	0, 1038
64	0, 1038
GRAPL	0, 1038
74	0, 1038
79	0, 200
84	0, 589
89	0, 589
94	0, 589
99	0, 589
104	0, 589
109	0, 589
114	0, 589
119	0, 1
124	0, 3928
129	0, 3928
134	0, 14218
139	0, 3928
144	0, 3928
149	0, 3928
154	0, 3928
159	0, 52
164	0, 10
169	0, 5
174	0, 5
179	0, 52

BLOCK	TRANS, TOTAL
5	0, 5
10	0, 5
15	0, 5
20	0, 5
25	0, 5
30	0, 5
35	1, 10
40	0, 589
45	0, 589
50	0, 14256
55	0, 1038
60	0, 1038
65	0, 1038
70	0, 1038
75	0, 1038
REBUN	0, 422
85	0, 589
90	0, 589
95	0, 15
100	0, 589
105	0, 589
110	0, 589
115	0, 589
CSTRT	0, 5
125	0, 3928
130	0, 3928
135	0, 14218
CHSAW	0, 194
145	0, 3928
150	0, 3928
155	0, 3928
160	0, 52
165	0, 10
170	0, 5
175	1, 5
180	0, 52

QUEUE STATISTICS

QUEUE NR	MAXIMUM CONTENTS	AVERAGE CONTENTS	TOTAL ENTRIES	ZERO ENTRIES	PERCENT ZEROS	AVERAGE TIME/TRANS	$ AVERAGE TIME/TRANS	TABLE NUMBER	CURRENT CONTENTS
SKBRK	1	.03	15	0	0.0	1777.67	1777.67	0	0
CPBUF	1	.00	589	588	99.8	146.00	146.00	0	0
CPBRK	1	.04	52	37	71.2	576.92	2000.00	0	0
CHSAW	1	.01	194	0	0.0	47.11	47.11	0	0
BFEMT	1	.04	3928	3530	89.9	14.39	142.04	0	0
EVCPR	1	.02	3928	3896	99.2	4.07	500.00	0	0
RDIST	1	.15	1178	0	0.0	85.00	85.00	0	0
WTRAV	1	.02	2076	302	14.5	10.14	11.87	0	0
ALIGN	1	.00	10	0	0.0	73.10	73.10	0	0
GRAPL	1	.09	1038	0	0.0	64.99	64.99	0	0
REBUN	1	.02	422	0	0.0	50.69	50.69	0	0
CHIP	1	.19	3928	0	0.0	36.20	36.20	0	0

SAVE VALUES

SAVEX

NR	VALUE
WKDAY	8
SKHR	4248
CPBRK	29952
AVDBH	550
MXSKD	150
FBGPT	33
CPVOL	52326133
CPTRE	14218
RDIST	353400
PDELY	50
SPEED	352
REBN1	50
CHSW2	9

NR	VALUE
DAYS	5
SKBRK	26655
BUCK	9118
AVHGT	43
NUMSK	1
FBTIU	150000
SKBUN	589
CPVNS	52
DBH	4
VNCON	0
GRPL1	65
REBN2	25
VNWT1	400

NR	VALUE
WDTIM	210769
SKNLN	0
CNPWD	54992
TRPAC	844
CMAX	12
SKGPH	400
SKTRE	14256
CPLOD	3928
WDIST	51848
VANCY	100000
GRPL2	20
DROP1	30
VNWT2	0

NR	VALUE
SKLND	44152
CPTIM	253650
CNPVN	15712
NUMFB	1
WBTU	8000000
SKVOL	52449291
SKADD	1038
NTBUF	38
ALIGN	10
ROAD	300
ALGN1	50
DROP2	15
CLSV1	100

NR	VALUE
SKTIA	2546351
CPHR	4230
AVVOL	3450000
FBTYP	0
LBCFT	65
CPGPH	570
SDIST	405248
BUFLM	500
REBUN	1500
HALF	85
ALGN2	50
CHSW1	47
CLSV2	0

Figure 9.—*Standard GPSS output.*

SKIDDER - TIME IN WOODS (MIN. X 100)

TABLE	ENTRIES IN TABLE	MEAN ARGUMENT	STANDARD DEVIATION	SUM OF ARGUMENTS
WDTIM	589	357.84	84.01	210769.

UPPER LIMIT	OBSERVED FREQUENCY	PERCENT OF TOTAL	CUMULATIVE PERCENTAGE	CUMULATIVE REMAINDER	MULTIPLE OF MEAN	DEVIATION FROM MEAN
250	80	13.58	13.6	86.4	.69	-1.28
300	91	15.45	29.0	71.0	.83	-.68
350	86	14.60	43.6	56.4	.97	-.09
400	142	24.11	67.7	32.3	1.12	.50
450	123	20.88	88.6	11.4	1.26	1.10
500	37	6.28	94.9	5.1	1.40	1.69
550	21	3.57	98.5	1.5	1.54	2.29
600	7	1.19	99.7	.3	1.68	2.88
650	1	.17	99.8	.1	1.82	3.48
700	1	.17	100.0	.0	1.96	4.07

NUMBER OF TREES PER SKIDDER BUNCH

TABLE	ENTRIES IN TABLE	MEAN ARGUMENT	STANDARD DEVIATION	SUM OF ARGUMENTS
BNTRE	589	24.20	6.03	14256.

UPPER LIMIT	OBSERVED FREQUENCY	PERCENT OF TOTAL	CUMULATIVE PERCENTAGE	CUMULATIVE REMAINDER	MULTIPLE OF MEAN	DEVIATION FROM MEAN
16	37	6.28	6.3	93.7	.66	-1.36
18	75	12.73	19.0	81.0	.74	-1.03
20	84	14.26	33.3	66.7	.82	-.69
22	64	10.87	44.1	55.9	.90	-.36
24	91	15.45	59.6	40.4	.99	-.03
26	64	10.87	70.5	29.5	1.07	.29
28	38	6.45	76.9	23.1	1.16	.62
30	32	5.43	82.3	17.7	1.24	.96
32	32	5.43	87.8	12.2	1.32	1.29
34	20	3.40	91.2	8.8	1.40	1.62
36	27	4.58	95.8	4.2	1.49	1.95
38	17	2.89	98.6	1.4	1.57	2.29
OVERFLOW	8	1.36	100.0	.0		

VOLUME PER SKIDDER BUNCH (CU. FT. X 100)

TABLE	ENTRIES IN TABLE	MEAN ARGUMENT	STANDARD DEVIATION	SUM OF ARGUMENTS
BNVOL	589	8904.80	2246.71	5244929.

UPPER LIMIT	OBSERVED FREQUENCY	PERCENT OF TOTAL	CUMULATIVE PERCENTAGE	CUMULATIVE REMAINDER	MULTIPLE OF MEAN	DEVIATION FROM MEAN
5000	1	.17	.1	99.8	.56	-1.74
5500	2	.34	.5	99.5	.61	-1.52
6000	20	3.40	3.9	96.1	.67	-1.29
6500	52	8.83	12.7	87.3	.73	-1.07
7000	59	10.02	22.8	77.2	.78	-.84
7500	60	10.19	32.9	67.1	.84	-.62
8000	51	8.66	41.6	58.4	.89	-.40
8500	51	8.66	50.3	49.7	.95	-.18
9000	48	8.15	58.4	41.6	1.01	.04
9500	46	7.81	66.2	33.8	1.07	.26
10000	39	6.62	72.8	27.2	1.12	.48
10500	21	3.57	76.4	23.6	1.18	.71
11000	29	4.92	81.3	18.7	1.24	.93
11500	23	3.90	85.2	14.8	1.29	1.16
12000	20	3.40	88.6	11.4	1.35	1.38
12500	10	1.70	90.3	9.7	1.40	1.60
13000	15	2.55	92.9	7.1	1.46	1.82
13500	13	2.21	95.1	4.9	1.52	2.05
14000	15	2.55	97.6	2.4	1.57	2.27
14500	8	1.36	99.0	1.0	1.63	2.49
15000	4	.67	99.7	.3	1.68	2.71
15500	2	.34	100.0	.0	1.74	2.94

Figure 10.—*Simulation output--productivity tables I.*

VOLUME PER CHIPPER LOAD (CU.FT. X 100)

TABLE CPVOL	ENTRIES IN TABLE	MEAN ARGUMENT	STANDARD DEVIATION	SUM OF ARGUMENTS
	3928	1332.13	815.81	5232613.

UPPER LIMIT	OBSERVED FREQUENCY	PERCENT OF TOTAL	CUMULATIVE PERCENTAGE	CUMULATIVE REMAINDER	MULTIPLE OF MEAN	DEVIATION FROM MEAN
200	145	3.69	3.7	96.3	.15	-1.39
400	243	6.19	9.9	90.1	.30	-1.14
600	291	7.41	17.3	82.7	.45	-.89
800	502	12.78	30.1	69.9	.60	-.65
1000	404	10.29	40.4	59.6	.75	-.40
1200	327	8.32	48.7	51.3	.90	-.16
1400	439	11.18	59.9	40.1	1.05	.08
1600	323	8.22	68.1	31.9	1.20	.32
1800	247	6.29	74.4	25.6	1.35	.57
2000	241	6.14	80.5	19.5	1.50	.81
2200	225	5.73	86.2	13.8	1.65	1.06
2400	146	3.72	89.9	10.1	1.80	1.31
2600	101	2.57	92.5	7.5	1.95	1.55
2800	76	1.93	94.5	5.5	2.10	1.80
3000	66	1.68	96.1	3.9	2.25	2.04
3200	50	1.27	97.4	2.6	2.40	2.29
3400	32	.81	98.2	1.8	2.55	2.53
3600	11	.28	98.5	1.5	2.70	2.78
3800	18	.45	99.0	1.0	2.85	3.03
4000	11	.28	99.2	.7	3.00	3.27
4200	8	.20	99.4	.5	3.15	3.52
4400	4	.10	99.5	.4	3.30	3.76
4600	8	.20	99.7	.2	3.45	4.01
4800	3	.07	99.8	.1	3.60	4.25
5000	4	.10	99.9	.0	3.75	4.50
5200	2	.05	100.0	.0	3.90	4.74
5400	1	.02	100.0	.0	4.05	4.99

CHIP TIME PER LOAD (MIN. X 100)

TABLE CPTIM	ENTRIES IN TABLE	MEAN ARGUMENT	STANDARD DEVIATION	SUM OF ARGUMENTS
	3928	56.99	71.65	223850.

UPPER LIMIT	OBSERVED FREQUENCY	PERCENT OF TOTAL	CUMULATIVE PERCENTAGE	CUMULATIVE REMAINDER	MULTIPLE OF MEAN	DEVIATION FROM MEAN
20	1160	29.53	29.5	70.5	.35	-.51
40	1189	30.27	59.8	40.2	.70	-.23
60	742	18.89	78.7	21.3	1.05	.04
80	331	8.43	87.1	12.9	1.40	.32
100	111	2.83	89.9	10.1	1.75	.60
120	71	1.81	91.8	8.2	2.11	.87
140	44	1.12	92.9	7.1	2.46	1.16
160	30	.76	93.6	6.4	2.81	1.44
180	32	.81	94.5	5.5	3.16	1.72
200	20	.50	95.0	5.0	3.51	2.00
220	31	.78	95.7	4.3	3.86	2.28
240	27	.68	96.4	3.6	4.21	2.55
260	27	.68	97.1	2.9	4.56	2.83
280	23	.58	97.7	2.3	4.91	3.11
300	13	.32	98.0	2.0	5.26	3.39
320	14	.35	98.4	1.6	5.62	3.67
340	9	.22	98.6	1.4	5.97	3.95
360	6	.15	98.8	1.2	6.32	4.23
380	4	.10	98.9	1.1	6.67	4.51
400	4	.10	99.0	1.0	7.02	4.79
420	4	.10	99.1	.9	7.37	5.07
440	1	.02	99.1	.8	7.72	5.35
460	1	.02	99.1	.8	8.07	5.62
480	2	.05	99.2	.8	8.42	5.90
520	10	.25	99.4	.5	9.12	6.46
540	13	.33	99.8	.2	9.48	6.74
560	6	.15	99.9	.0	9.83	7.02
580	2	.05	100.0	.0	10.18	7.30
OVERFLOW	1	.02	100.0	.0		

Figure 11.—*Simulation output--productivity tables II.*

Table 6.—*Productivity and delays of two system configurations*

	System 1		System 2	
	One skidder	One chipper	Two skidders	One chipper
Total machine hours worked	42.39	42.21	81.06	40.42
Percent productive time	89.7	56.6	59.6	75.4
Percent nonproductive time				
Total delay	10.3	43.3	40.4	24.6
Breaks	10.3	11.8	6.6	12.4
Wait to drop wood	0.0		33.8	
Wait for wood to chip		21.9		0.0
Wait for bucking		3.3		4.6
Wait for vans		6.3		7.6
Total trees	14,268		17,843	
Total vans filled	52		65	
Total tons processed	1,706		2,132	

APPENDIX A
VARIABLE LISTS AND DEFINITIONS

IMPLICIT TIME UNIT—centi-minute
MODEL SEGMENTS, TRANSACTIONS, AND PARAMETERS

Segment 1—TIMER
Transactions—1 time keeper.
Parameters—None.

Segment 2—SKIDDER(S)
Transactions—One for each skidder.
Parameters
P1—not used.
P2—clock time.
P3—total number of trees in skid load.
P4—total d.b.h. (inches) in skid load.
P5—total volume of skid load.
P6—number of feller/buncher bunches combined in this skid load.
P7—road distance.
P8—woods distance.
P9—number of trees in feller/buncher bunch.
P10—counter for d.b.h. loop.
P11—total sum of diameter in feller/buncher bunch.
P12—total volume of feller/buncher bunch.

Segment 3—CHIPPER
Transactions—One chipper-loader. When it splits, parent transaction remains as chipper while offspring becomes full van.
Parameters
P1—clock time.
P2—number of trees in chipper-grapple load.
P3—volume of load.
P4—sum of diameter of load (inches).
P5—loop counter.

FACILITY

CPBUF Chipper buffer—area where skidders drop logs within reach of chipper.

FUNCTIONS

DBH Distribution of diameters in the stand—used by skidder.
DIAM Identical diameter distribution—used by chipper.
NGRAP Distribution of the number of trees per chipper—grapple load.

NTBUN Distribution of number of trees in each bunch left by feller/buncher.
SNORM Used to obtain a normal distribution for sampling.
WDIST Distribution of bunches in the woods.

QUEUES

ALIGN Time skidder spends aligning bunches.
BFEMT Time chipper waits for wood.
CHIP Chipping time.
CHSAW Time spent bucking logs.
CPBRK Time chipper spends on break.
CPBUF Skidder time waiting to drop load.
EVCPR Chipper time waiting for empty van.
GRAPL Skidder grapple time.
RDIST Skidder travel time on road.
REBUN Time spent rebunching a skid load.
SKBRK Time skidders spend on break.
WTRAV Skidder travel time in woods.

SAVEVALUES

ALGN1 Time to align bunch—mean (centi-minutes).
ALGN2 Time to align bunch—standard deviation (centi-minutes).
ALIGN Percent of bunches needing alignment. NOTE: Must be three digits in terms of thousandths.
AVDBH Average stand diameter (inches x 10).
AVHGT Average tree height (feet).
AVVOL Average stand volume (cubic feet x 100).
BUCK Chipper delay time due to bucking (centi-minutes).
BUFLM Available room at chipper (number of logs).
CHSW1 Chain saw time to buck log—mean (centi-minutes).
CHSW2 Chain saw time—standard deviation (centi-minutes).
CLSV1 Time to close van—mean (centi-minutes).
CLSV2 Time to close van—standard deviation (centi-minutes).
CMAX Maximum chipper load (number of trees).
CNPVN Chipper nonproductive time waiting for vans (centi-minutes).
CNPWD Chipper nonproductive time waiting for wood to chip (centi-minutes).
CPBRK Chipper time spent on breaks (centi-minutes).
CPGPH Chipper fuel consumption (gallons/hour).
CPHR Total chipper time (hours x 100).
CPLOD Total number of chipper-grapple loads chipped.
CPTIM Total chipper time (centi-minutes).
CPTRE Total trees chipped.
CPVNS Total vans filled.
CPVOL Total volume chipped (cubic feet x 100).
DAYS Number of current day.
DBH Diameter of current tree (inches).
DROP1 Time needed for skidder to drop bunch—mean (centi-minutes).
DROP2 Time needed to drop bunch—standard deviation (centi-minutes).
FBGPT Feller/buncher fuel usage (gallons/ton).
FBTU Btu's in fuel per gallon.
FBTYP Feller/buncher type. 0 = tracked; 1 = rubber tired.
GRPL1 Skidder grapple time/bunch—mean (centi-minutes).
GRPL2 Grapple time/bunch—standard deviation (centi-minutes).
HALF Skid load limit to add more to the load (sum of diameters).
LBCFT Density of wood (pounds/cubic feet).
MXSKD Maximum skidder grapple load—total sum of diameter (inches).
NTBUF Current number of trees at the chipper.
NUMFB Number of feller/bunchers used to fell trees.
NUMSK Number of skidders in operation.
PDELY Percent of chipper loads requiring sawing. NOTE: Must be three digits in terms of thousandths.
RDIST Skid road/track distance (feet).
REBN1 Time needed to rebunch skid load—mean (centi-minutes).
REBN2 Time needed to rebunch—standard deviation (centi-minutes).
REBUN Percent of single bunches needing rebunching before hauling. NOTE: Must be three digits in terms of thousandths.
ROAD Skid distance along road/track (feet).
SDIST Total skid distance (feet).
SKADD Number of feller/buncher bunches collected into this skid load.
SKBRK Skidder time on break (centi-minutes).
SKBUN Total bunches skidded.
SKGPH Skidder fuel consumption (gallons/hour).
SKHR Total skidder time on job (hours x 100).
SKLND Skidder time spent at landing (centi-minutes).
SNLN Skidder time at landing—nonproductive.
SKTIM Total skidder time—all machines (centi-minutes).
SKTRE Total number of trees skidded.
SKVOL Total volume skidded—all machines.
SPEED Skidder travel speed on road/track (feet/minutes).
TRPAC Trees per acre.

VANCY Van capacity (cubic feet x 100).
VNCON Van contents (cubic feet x 100).
VNWT1 Time needed to replace full van with empty van—mean (centi-minutes).
VNWT2 Time needed to replace van—standard deviation (centi-minutes).
WBTU Btu's in wood per ton.
WDIST Total distance skidders have traveled through the woods (feet).
WDTIM Skid time in the woods (centi-minutes).
WKDAY Length of workday (hours).

SWITCHES

CBRK Set by chipper to tell skidders that chipper is on break.
CHIPR Set by chipper to indicate it is on the job.
COFFE Set by timer to indicate coffee break time.
DAY Set by timer to indicate start of shift.
EVCPR Set by vans to indicate empty van available.
LUNCH Set by timer to indicate lunch time.

TABLES

BNDIA Total sum of diameter of skid bunch (inches).
BNTRE Number of trees per skid bunch.
BNVOL Volume of skidder loads (cubic feet x 100).
CPTIM Time to chip each load (centi-minutes).
CPVOL Volume in each chip load (cubic feet x 100).
SKILN Time skidder is at landing on each trip (centi-minutes).
WDTIM Time skidder is in woods on each trip (centi-minutes).

BOOLEAN VARIABLES

ADD Conditions under which the skidder will add another bunch before skidding to chipper.
DROP Allows skidder to drop trees if there is room at chipper or if chipper is done for the day.

VARIABLES

ALIGN Time needed for skidder to align bunch if needed (centi-minutes).
BREAK Time between breaks (centi-minutes).
BUCK Total delay due to bucking logs (centi-minutes).
CHIP Time to chip this load (centi-minutes).
CHSAW Time needed to buck a log (centi-minutes).
CLSVN Time to close full van (centi-minutes).
CNPVN Chipper nonproductive time spent waiting for vans (centi-minutes).
CNPWD Chipper nonproductive time waiting for wood (centi-minutes).
CPBRK Time chipper spends on break (centi-minutes).
CPHR Total chipper time (hours x 100).
DROP Time for skidder to drop bunch (centi-minutes).
GRAPL Skidder-grapple time per bunch (centi-minutes).
NGRAP Number of trees the chipper-grapple takes each load.
NIGHT Remainder of 24 hours after work shift (centi-minutes).
NTBUN Number of trees feller/buncher left in each bunch.
RDIST Skid road/track distance (feet).
REBUN Time needed to rebunch skid load (centi-minutes).
RTRAV Skidder travel time along skid road (centi-minutes).
SKBRK Time skidders spend on break (centi-minutes).
SKHR Total skidder time—all machines (hours x 100).
SKNLN Total nonproductive time for skidders at landing (centi-minutes).
SKTIM Total skid time—all machines (centi-minutes).
TVOL Volume of each tree in terms of d.b.h. (cubic feet x 100).
VNWAT Time needed to change vans (centi-minutes).
WDIST Distance from skid road/trail to bunches (feet).
WKDAY Length of work shift (centi-minutes).
WTRAV Skidder travel time through woods (centi-minutes).

APPENDIX B
PROGRAM LISTING

```
*MTU*GPSSX8.GPSSX8,S ,TPF$,SKDCHP
GPSSX8 V2.6 RL72-8 06/26/81 08:49:39
    1.              *- - - - - - - - - - - - - - - - - - - - - - - - - - - - - - - - - - - - - - - -
    2.              *
    3.              *
    4.              *     SKIDDER CHIPPER SYSTEM SIMULATION      DOCUMENTED 81
    5.              *
    6.              *       U.S. FOREST SERVICE, NORTH CENTRAL FOREST EXPERIMENT STATION
    7.              *       MARKETING PROJECT, DULUTH, MINNESOTA
    8.              *       ENGINEERING PROJECT, HOUGHTON, MICHIGAN
    9.              *
   10.              *    AUTHORS:    DENNIS P. BRADLEY
   11.              *                SHARON A. WINSAUER
   12.              *
   13.              *- - - - - - - - - - - - - - - - - - - - - - - - - - - - - - - - - - - - - - - -
   14.              *
   15.              *
   16.              *- - - - - - - - - - - - - - - - - - - - - - - - - - - - - - - - - - - - - - - -
   17.              *
   18.              *      GENERAL FUNCTIONS NEEDED IN MODEL
   19.              *
   20.              *- - - - - - - - - - - - - - - - - - - - - - - - - - - - - - - - - - - - - - - -
   21.              *
   22.              *
   23.              * * *  FN$SNORM IS USED TO OBTAIN A SAMPLING OF AN APPROXIMATELY
   24.              *       NORMAL DISTRIBUTION OF MEAN 0 AND STANDARD DEV 1
   25.              *
   26.              *       NOTE: TO AVOID DATA LOSS FROM INTEGERIZATION,
   27.              *       VALUES HAVE BEEN MULTIPLIED BY 10.
   28.              *
   29.              *       USE MEAN + ST. DEV*FN$SNORM/10
   30.              *
   31.              *       NOTE: THE LOWER END OF THE FUNCTION HAS BEEN
   32.              *       TRUNCATED TO AVOID NEGATIVE ADVANCE BLOCKS
   33.              *       WHEN STANDARD DEVIATIONS ARE LARGE
   34.              *
   35.              SNORM FUNCTION   RN2,C20
   36.              0,-15/.0668,-15/.1151,-12/.1587,-10/.2119,-8/.2742,-6/.3446,-4
   37.              .4207,-2/.5,0/.5793,2/.6544,4/.7258,6/.7881,8/.8413,10/.8849,12
   38.              .9332,15/.9772,20/.9938,25/.9986,30/.9999,40/1.,50
   39.              *
   40.              *
```

```
                /- - - - - - - - - - - - - - - - - - - - - - - - - - - - - - - - - - - - - -
                *
                *                    MASTER TIMER AND REPORT GENERATOR
                * - - - - - - - - - - - - - - - - - - - - - - - - - - - - - - - - - - - - - -
                *
                *       THIS SEGMENT CONTROLS THE START AND STOP
                *       OF THE SKIDDERS AND CHIPPERS, THE
                *       HOURS WORKED PER DAY, X$WKDAY, AND
                *       THE NUMBER OF DAYS WORKED
                *       (ARGUMENT A ON THE START CARD) .
                *
                *       IT ALSO CALCULATES THE OUTPUT
                *       VALUES SENT TO HELP BLOCKS.
                *
                 WKDAY  VARIABLE   X$WKDAY*6000                 WORKDAY IN CENTIMINUTES
                 NIGHT  VARIABLE   (24-X$WKDAY)*6000            REST OF 24 HOURS IN CENTIMINUTES
                 BREAK  FVARIABLE  V$WKDAY/4                    TIME BETWEEN BREAKS
                *
                 TIMER  GENERATE   ,,,1,12
               1 NXDAY  SAVEVALUE  DAYS+,1                      NUMBER OF CURRENT WORKING DAY
               2        LOGIC S    DAY                         TIME TO START WORK
               3        ADVANCE    V$BREAK
               4        LOGIC S    COFFE                       TIME FOR COFFEE BREAK
               5        ADVANCE    V$BREAK
               6        LOGIC S    LUNCH                       LUNCH TIME
               7        ADVANCE    V$BREAK
               8        LOGIC S    COFFE                       TIME FOR TEA
               9        ADVANCE    V$BREAK
              10        LOGIC R    DAY                         TIME TO QUIT
              11        ADVANCE    V$NIGHT
              12
                *
                *
                * * * *  HELP BLOCKS GENERATE REPORT AT END OF EACH 24 HOUR DAY
                *
                *
                * * * * REPORT VARIABLES
                *
                 SKTIM  VARIABLE   X$WDTIM+X$SKLND              TOTAL SKIDDER TIME (CENTIMINUTES)
                 SKHR   VARIABLE   X$SKTIM/60                   TOTAL SKIDDER TIME (HOURS)
                *                                               SKIDDER NON-PRODUCTIVE TIME
                 SKBRK  FVARIABLE  QC$SKBRK*QT$SKBRK              - ON BREAK
                 SKNLN  FVARIABLE  QC$CPBUF*QT$CPBUF              - AT LANDING
                *
                *
                        SAVEVALUE  SKTIM,V$SKTIM
              13        SAVEVALUE  SKHR,V$SKHR
              14        SAVEVALUE  SKBRK,V$SKBRK
              15        SAVEVALUE  SKNLN,V$SKNLN
              16
                *
                *
                 CPHR   FVARIABLE  X$CPTIM/60                   TOTAL CHIPPER HOURS
                *                                               CHIPPER NON-PRODUCTIVE TIME
                 CPBRK  FVARIABLE  QC$CPBRK*QT$CPBRK              - ON BREAK
                 BUCK   FVARIABLE  QC$CHSAW*QT$CHSAW              - WAITING FOR BUCKING
                 CNPWD  FVARIABLE  QC$BFEMT*QT$BFEMT              - WAITING FOR WOOD
                 CNPVN  FVARIABLE  QC$EVCPR*QT$EVCPR              - WAITING FOR VANS
                *
                        SAVEVALUE  CPHR,V$CPHR
              17        SAVEVALUE  CPBRK,V$CPBRK
              18        SAVEVALUE  BUCK,V$BUCK
              19        SAVEVALUE  CNPWD,V$CNPWD
              20        SAVEVALUE  CNPVN,V$CNPVN
              21
```

```
                /
                * * * *  STAND DATA AND MACHINE CHARACTERISTICS REPORT
                *
                *              VOL/ACRE, AVE DBH, TREE HT, TREES/ACRE
           22         HELP        SLSYS,X$AVVOL,X$AVDBH,X$AVHGT,X$TRPAC
                *
                *          NUMBER OF FB, FB TYPE
           23         HELP        SLSYS,X$NUMFB,X$FBTYP
                *
                *          MAX BUNCH SIZE, NUM OF SKID, CHIPPER LOAD MAX
           24         HELP        SLSYS,X$MXSKD,X$NUMSK,X$CMAX
                *
                *          BTU/TON WOOD, WOOD DENSITY, FB FUEL USAGE GAL/TON, FUEL BTU
           25         HELP        SLSYS,X$WBTU,X$LBCFT,X$FBGPT,X$FBTU
                *
                *          SKIDDER HOURS, SKIDDER GALLONS/HOUR, SKIDDED VOLUME
           26         HELP        SLSYS,X$SKHR,X$SKGPH,X$SKVOL
                *
                *          CHIPPER HOURS, CHIPPER GALLONS/HOUR, CHIPPED VOLUME
           27         HELP        SLSYS,X$CPHR,X$CPGPH,X$CPVOL
                *
                *
                * * * *  SKIDDER PRODUCTION REPORT
                *
                *          SKIDDER HOURS, NUMBER OF SKIDDERS, BUNCHES SKIDDED, TREES SKIDDED
           28         HELP        SKIDR,X$SKHR,X$NUMSK,X$SKBUN,X$SKTRE
                *
                *          VOLUME SKIDDED, TOTAL # OF FB BUNCHES, TOTAL SKID DISTANCE
           29         HELP        SKIDR,X$SKVOL,X$SKADD,X$SDIST
                *
                *          WOODS TIME, LANDING TIME, NON-PRODUCTIVE LANDING TIME,BREAK TIME
           30         HELP        SKIDR,X$WDTIM,X$SKLND,X$SKNLN,X$SKBRK
                *
                *          POUNDS/CUFT OF WOOD, SKIDDER GALLONS/HOUR
           31         HELP        SKIDR,X$LBCFT,X$SKGPH
                *
                *
                * * * *  CHIPPER PRODUCTION REPORT
                *
                *          CHIPPER HOURS WORKED, POUNDS/CUFT OF WOOD, NON-PRODUCTIVE TIME
                *          WAITING FOR WOOD, NON-PRODUCTIVE TIME WAITING FOR VANS,
                *          CHIPPER GALLONS/HOUR
           32         HELP        CHIPR,X$CPHR,X$LBCFT,X$CNPWD,X$CNPVN,X$CPGPH
                *
                *          TREES CHIPPED, VOLUME CHIPPED, NUMBER OF FULL VANS, NUMBER OF
                *          CHIPPER LOADS, BUCKING TIME, BREAK TIME
           33         HELP        CHIPR,X$CPTRE,X$CPVOL,X$CPVNS,X$CPLOD,X$BUCK
           34         HELP        CHIPR,X$CPBRK
                *
                *
           35         SPLIT       1,NXDAY
                *
          OUTPT TERMINATE  36      1
```

```
                *
                * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * *
                *
                * * SKIDDER SEGMENT * * *
                *
                * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * *
                *
                *    THIS SEGMENT MODELS GRAPPLE TYPE SKIDDER(S)
                *    SKIDDING BUNCHES PREVIOUSLY LAID DOWN BY A FELLER BUNCHER.
                *    THE SKIDDER TRAVELS ALONG A SKID ROAD/TRAIL TO THE WOODS,
                *    THEN TRAVELS THROUGH THE WOODS TO GRAPPLE A BUNCH.
                *    IT CAN COLLECT MULTIPLE FB BUNCHES BEFORE RETURNING TO
                *    THE LANDING.
                *
                * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * *
                *
                *
                * * PARAMETER DEFINITIONS
                *
                *    P1
                *    P2    CLOCK TIME
                *    P3    TOTAL NO OF TREES IN BUNCH
                *    P4    TOTAL DBH OF BUNCHES COMBINED
                *    P5    TOTAL VOL OF BUNCHES COMBINED
                *    P6    NUMBER OF BUNCHES GRAPPLED
                *    P7    ROAD DISTANCE
                *    P8    WOOD DISTANCE
                *    P9    NUMBER OF TREES IN NEXT BUNCH
                *    P10   COUNTER
                *    P11   SUM OF DIA OF NEXT BUNCH
                *    P12   TOT VOL OF NEXT BUNCH
                *
                *
                * * DEFINING VARIABLES FOR SKIDDERS
                *
                DROP  BVARIABLE  X$NTBUF'LE'X$BUFLM+LR$CHIPR
                *                                          TRUE IF ROOM TO DROP TREES
                *                                          OR CHIPPER HAS QUIT
                *
                *
                * * GENERATE SKIDDERS
                *
37              SKDDR GENERATE   ,,,X$NUMSK,8,12
                *
                *    TIME TO WORK? IF NOT, WAIT
                *
38              START GATE LS    CHIPR                   WAIT UNTIL CHIPPER IS WORKING
39                    MARK       2
40                    ASSIGN     7,V$RDIST               ROAD DISTANCE
41                    QUEUE      RDIST
42                    ADVANCE    V$RTRAV                 TRAVEL TO WOODS
43                    DEPART     RDIST
44                    SAVEVALUE  SDIST+,P7               TOTAL DISTANCE TRAVELED
45                    SAVEVALUE  RDIST+,P7               TOTAL ROAD DISTANCE
                *
                *    SKIDDER IN WOODS   DETERMINE CHARACTERISTICS OF BUNCH
                *
46              WOODS ASSIGN     9,V$NTBUN               NUMBER OF TREES IN NEXT BUNCH
47                    ASSIGN     10,P9
48                    ASSIGN     8,V$WDIST               WOODS DISTANCE TO BUNCH
                *
49              NDBH  SAVEVALUE  DBH,FN$DBH              FIND SUM OF DIAMETER AND
50                    ASSIGN     11+,X$DBH               TOTAL VOLUME OF NEXT BUNCH
51                    ASSIGN     12+,V$TVOL
52                    LOOP       10,NDBH
```

```
                /      ADD ON FB BUNCH
                *
53              ASSIGN      3+,P9
54              ASSIGN      4+,P11
55              ASSIGN      5+,P12
56              ASSIGN      6+,1
                *
57              ASSIGN      9,0
58              ASSIGN      11,0
59              ASSIGN      12,0
                *
                *       TRAVEL TO BUNCH AND GRAPPLE IT
                *
60              QUEUE       WTRAV
61              ADVANCE     V$WTRAV
62              DEPART      WTRAV
63              SAVEVALUE   SDIST+,P8
64              SAVEVALUE   WDIST+,P8
                *
                *       IF NECESSARY - ALIGN BUNCH
                *
65              TRANSFER    .X$ALIGN,GRAPL,ALIGN
                *
66    ALIGN     QUEUE       ALIGN
67              ADVANCE     V$ALIGN
68              DEPART      ALIGN
                *
                *       GRAPPLE BUNCH
                *
69    GRAPL     QUEUE       GRAPL
70              ADVANCE     V$GRAPL
71              DEPART      GRAPL
                *
                *       TRAVEL TO COLLECTION POINT (ROAD) DIST = P8
                *
72              QUEUE       WTRAV
73              ADVANCE     V$WTRAV
74              DEPART      WTRAV
75              SAVEVALUE   SDIST+,P8
76              SAVEVALUE   WDIST+,P8
                *
                *       SHOULD SKIDDER TAKE ANOTHER BUNCH? IS SO RETURN TO WOODS
77              TEST NE     BV$ADD,1,WOODS          IF BV$ADD=1 RETURN FOR A BNCH
                *
78              TEST LE     P6,1,REBUN      MUST REBUNCH IF MORE THAN ONE BUNCH
                *
                *       DOES  SKIDDER NEED TO REBUNCH
                *
                *
79              TRANSFER    .X$REBUN,SKLND,REBUN
                *
80    REBUN     QUEUE       REBUN                       DROP TREES AND REBUNCH
81              ADVANCE     V$REBUN
82              DEPART      REBUN
```

```
                *
                *       SKID TO LANDING
                *
           83   SKLND  QUEUE       RDIST
           84          ADVANCE     V$RTRAV
           85          DEPART      RDIST
           86          SAVEVALUE   SDIST+,P7
           87          SAVEVALUE   RDIST+,P7
                *
                *       TABULATE  WOODS TIME
                *
           88          SAVEVALUE   WDTIM+,MP2
                *
                *       TABULATE DATA ON BUNCH
           89          TABULATE    WDTIM
           90          TABULATE    BNTRE
           91          TABULATE    BNVOL
           92          TABULATE    BNDIA
                *
                *
                *     SKIDDER AT LANDING
                *     SKIDDER MUST EITHER DROP LOAD, WAIT FOR ROOM AT CHIPPER TO DROP
                *     LOAD OR QUIT FOR THE DAY
                *
           93   LAND   MARK        2                    KEEP TRACK OF LANDING TIME
           94          GATE LS     CBRK,SWORK           IF CHIPPER IS ON BREAK
           95          QUEUE       SKBRK                SKIDDERS CAN
           96          GATE LR     CBRK                 TAKE BREAK
           97          DEPART      SKBRK
                *
           98   SWORK  QUEUE       CPBUF
           99          TEST E      BV$DROP,1            WAIT FOR ROOM TO DROP TREES OR
                *                                       DROP IF CHIPPER HAS QUIT
          100          SEIZE       CPBUF
          101          DEPART      CPBUF
          102          ADVANCE     V$DROP
          103          SAVEVALUE   NTBUF+,P3        ADD THIS LOAD TO CHIPPER BUFFER
          104          RELEASE     CPBUF
                *
          105          SAVEVALUE   SKLND+,MP2           SKIDDER TIME AT LANDING
                *
                *       TABULATE DATA ON BUNCH
                        TABULATE    SKTLN
          106           SAVEVALUE   SKTRE+,P3
          107           SAVEVALUE   SKVOL+,P5
          108           SAVEVALUE   SKBUN+,1
          109           SAVEVALUE   SKADD+,P6
          110
                *
                *
                        ASSIGN      3,0
          111           ASSIGN      4,0
          112           ASSIGN      5,0
          113           ASSIGN      6,0
          114           ASSIGN      7,0
          115           ASSIGN      8,0
          116
                *
                *
          117   WAIT   TRANSFER    ,START
```

```
*
* * * *
```

```
                *       RECORD STATISTICS OF CHIPPING
                *
          146           SAVEVALUE   CPTIM+,MP1
          147           TABULATE    CPVOL
          148           TABULATE    CPTIM
          149           SAVEVALUE   CPLOD+,1
          150           SAVEVALUE   CPTRE+,P2
          151           SAVEVALUE   CPVOL+,P3
                *
                *       ADD CHIPPED VOL TO VAN
                *
          152           SAVEVALUE   VNCON+,P3
          153           ASSIGN      2,0
          154           ASSIGN      3,0
          155           ASSIGN      4,0
                *
                *       SEE IF THE VAN IS FULL
                *
          156           TEST GE     X$VNCON,X$VANCY,NEWLD   VAN NOT FULL GET NEW LOAD
                *
                *       VAN IS FULL - ONE TRANSACTION GOES TO CLOSE VAN AND
                *       LINKS IT ON FULL VAN CHAIN TO BE HAULED
                *
                *       THE PARENT TRANSACTION REMAINS THE CHIPPER
                *
          157           LOGIC R     EVCPR
          158   FULVN   SPLIT       1,LNKVN
          159           MARK        1
          160           QUEUE       CPBRK                   CHECK FOR BREAK TIME
                *
          161           GATE LS     COFFE,NOBRK
          162           LOGIC S     CBRK
          163           ADVANCE     1500                    TAKE BREAK
          164           LOGIC R     COFFE
          165           LOGIC R     CBRK
          166   NOBRK   GATE LS     LUNCH,CDONE
          167           LOGIC S     CBRK
          168           ADVANCE     3000                    STOP FOR LUNCH
          169           LOGIC R     LUNCH
          170           LOGIC R     CBRK
                *
          171   CDONE   DEPART      CPBRK                   IS IT END OF SHIFT?
          172           SAVEVALUE   CPTIM+,MP1              IF NOT END OF DAY GET NEW LOAD
          173           GATE LR     DAY,NEWLD
          174           LOGIC R     CHIPR                   CHIPPER DONE FOR TODAY
          175           TRANSFER    ,CSTRT
                *
          176   LNKVN   SAVEVALUE   VNCON,0
          177           SAVEVALUE   CPVNS+,1                CLOSE THE VAN
          178           ADVANCE     V$CLSVN
          179           ADVANCE     V$VNWAT                 BRING IN ANOTHER VAN
          180           LOGIC S     EVCPR
          181           TERMINATE
                *
                *
```

```
451.
452.                /
453.                *    *    *    TABLE DEFINITIONS    *    *    *
454.                *
455.                 WDTIM TABLE      MP2,0,50,20              SKIDDER TIME IN WOODS
456.                 SKTLN TABLE      MP2,0,25,20              SKIDDER TIME AT LANDING
457.                *
458.                 BNTRE TABLE      P3,0,2,20                NO. OF TREES PER SKIDDER LOAD
459.                 BNVOL TABLE      P5,0,500,40              VOLUME PER SKID LOAD
460.                 BNDIA TABLE      P4,0,10,30               SUM OF DIAMETER/SKIDDER LOAD
461.                *
462.                 CPVOL TABLE      P3,0,200,30              VOLUME PER CHIPPER LOAD
463.                 CPTIM TABLE      MP1,0,20,30              TIME PER CHIPPER LOAD
464.                *
465.                *
466.                *   *  *  FUNCTION AND VARIABLE DEFINITIONS  *  *  *
467.                *
468.                * * * DEFINING VARIABLES FOR STAND
469.                *
470.                 NTBUN FVARIABLE  FN$NTBUN
471.                 TVOL  FVARIABLE  (133*X$DBH*X$DBH-283)/10  TREE VOL IN TERMS OF DIA
472.                 RDIST FVARIABLE  X$ROAD                   ROAD DISTANCE
473.                 WDIST FVARIABLE  FN$WDIST                 WOODS DISTANCE
474.                *
475.                * * * DEFINING VARIABLES FOR SKIDDER
476.                *
477.                 ADD   BVARIABLE  P4'L'X$HALF              IF LESS THAN 1/2 LOAD ADD MORE
478.                 RTRAV FVARIABLE  P7*100/X$SPEED           TRAVEL TIME ON ROAD
479.                 WTRAV FVARIABLE  P8*150/X$SPEED           TRAVEL IN WOODS 2/3 ROAD SPEED
480.                 GRAPL FVARIABLE  X$GRPL1+X$GRPL2*FN$SNORM/10    TIME TO GRAPPLE
481.                 ALIGN FVARIABLE  X$ALGN1+X$ALGN2*FN$SNORM/10    ALIGN BUNCH
482.                 REBUN FVARIABLE  X$REBN1+X$REBN2*FN$SNORM/10
483.                 DROP  FVARIABLE  X$DROP1+X$DROP2*FN$SNORM/10    TIME TO DROP BUNCH
484.                *
485.                * * * *  DEFINING VARIABLES FOR CHIPPER/LOADER
486.                *
487.                 NGRAP FVARIABLE  FN$NGRAP
488.                 CHIP  FVARIABLE  P2*10                          CHIP TIME IN CENTIMIN
489.                 CHSAW FVARIABLE  X$CHSW1+X$CHSW2*FN$SNORM/10
490.                 VNWAT FVARIABLE  X$VNWT1+X$VNWT2*FN$SNORM/10    VAN WAIT TIME
491.                 CLSVN FVARIABLE  X$CLSV1+X$CLSV2*FN$SNORM/10    TIME TO CLOSE VAN
492.                *
493.                *
494.                * * * STAND FUNCTIONS
495.                 NTBUN FUNCTION   RN3,D24                  NUMBER OF TREES PER BUNCH
496.                .004,2/.025,3/.06,4/.09,5/.15,6/.20,7/.24,8/.30,9/.35,10/.39,11/.45,12
497.                .52,13/.58,14/.61,15/.66,16/.70,17/.73,18/.76,19/.80,20/.84,21/.87,22
498.                .91,23/.95,24/1.0,25
499.                *
500.                 WDIST FUNCTION   RN3,C14                  WOODS DISTANCE FOR SKIDDER
501.                .0/.23,5/.35,10/.42,15/.53,20/.63,25/.72,30/.77,35/.79,40/.82,45
502.                .86,50/.88,55/.90,60/1.00,100
503.                *
504.                * * * SKIDDER FUNCTIONS
505.                 DBH   FUNCTION   RN4,D7                   TREE DIAMETER INCHES
506.                .05,3/.27,4/.58,5/.82,6/.96,7/.99,8/1.0,9
```

```
/
* * * CHIPPER FUNCTIONS
*
 DIAM  FUNCTION   RN5,D7                              TREE DIAMETER FOR CHIPPING
.05,3/.27,4/.58,5/.82,6/.96,7/.99,8/1.0,9
*
 NGRAP FUNCTION   RN3,D10                             GRAPPLE LOAD FOR CHIPPER
.12,1/.31,2/.49,3/.66,4/.81,5/.89,6/.95,7/.98,8/.99,10/1.00,12
*
*
*    *    *   INITIAL VALUES FOR THIS RUN    *    *    *
*
        INITIAL     X$WKDAY,8                        HRS  IN WKDAY
*
        INITIAL     X$AVHGT,43/X$AVDBH,550   STAND DATA
        INITIAL     X$AVVOL,345000
        INITIAL     X$TRPAC,844
        INITIAL     X$ROAD,300                       AVE ONE-WAY DISTANCE
        INITIAL     X$LBCFT,65                       LB OF  WOOD /CU  FT
        INITIAL     X$WBTU,8000000                   BTU   PER TON  OF  WOOD
        INITIAL     X$FBTU,150000                    BTU  IN  FUEL PER GAL
*
        INITIAL     X$FBTYP,0/X$NUMFB,1      TRACKED TYPE FELLER BUNCHER
        INITIAL     X$FBGPT,33               FELLER BUNCHER GAL/TON * 100
*
        INITIAL     X$NUMSK,1                          NUMBER OF SKIDDERS
        INITIAL     X$MXSKD,150/X$HALF,85    MAX SKID BUNCH SUM OF DIA
        INITIAL     X$SKGPH,400                      GAL/HRX100
        INITIAL     X$SPEED,352              SKID TRAVEL SPEED FT/MIN
        INITIAL     X$GRPL1,65/X$GRPL2,20            TIME TO POSITION & GRAPPLE
        INITIAL     X$ALGN1,50/X$ALGN2,30    TIME TO ALIGN BUNCH
        INITIAL     X$ALIGN,010                      % OF BUNCHES TO BE ALIGNED
        INITIAL     X$DROP1,30/X$DROP2,15            TIME TO DROP BUNCH
        INITIAL     X$REBN1,50/X$REBN2,25    TIME TO REBUNCH
        INITIAL     X$REBUN,150                      % OF TIME HE REBUNCHES 1 LOAD
*
        INITIAL     X$BUFLM,50          LIMIT - TREES AT CHIPPER
*
        INITIAL     X$CMAX,12                MAX CHIPPER LOAD
        INITIAL     X$CPGPH,570              LARGE CHIPPER GAL/HR.
        INITIAL     X$CHSW1,47/X$CHSW2,9     CHAIN SAW DELAY TIME
        INITIAL     X$PDELY,050
*
        INITIAL     X$VANCY,100000
        INITIAL     X$CLSV1,100                      CLOSE VAN TIME
        INITIAL     X$VNWT1,400                      VAN WAIT TIME
*
        RMULT       ,,,17,17
        START       5,,5,1
        END
```

```
      SUBROUTINE SLSYS(IX)
      DIMENSION IX(5)
      DATA I/0/
      REAL MXSKD
C
    1 FORMAT(1H1,54X,'SAWLOG  SORTING  '
     A 'SIMULATOR'/1H0,58X,'DEVELOPED  BY  THE'/1H ,46X,'NORTH CENTRAL '
     B,'FOREST  EXPERIMENT  STATION'/1H ,44X,'FOREST  SERVICE, U. S. DEP
     CT.  OF  AGRICULTURE'/1H ,29X, 'FOREST  PRODUCTS  MARKETING  AND  U
     DTILIZATION  PROJECT,  DULUTH,  MINNESOTA'/1H ,61X,'AND  THE'/1H,40
     EX,'FOREST  ENGINEERING  LABORATORY, HOUGHTON,  MICHIGAN'/1H ,62X,
     F'AUTHORS '/1H ,52X,'DENNIS P. BRADLEY, ECONOMIST'/1H ,51X,'SHARON
     GA. WINSAUER, PROGRAMMER'/)
C
    2 FORMAT(1H0,'I.  STAND CHARACTERISTICS.',/
     A                    1H0,F12.2,' CUFT., AVERAGE VOLUME',
     B' PER ACRE.'/1H0,F12.2,' INCHES, AVERAGE DBH.'/1H0,F12.2,' FEET,',
     C' AVERAGE TREE HEIGHT.'/1H0,F12.2,' AVERAGE NUMBER OF TREES ',
     D'PER ACRE.'/1H0,F12.2,' FEET, AVERAGE TREE SPACING.'/)
C
    3 FORMAT(1H0,'II.  SYSTEM CHARACTERISTICS AS SPECIFIED BY THE ',
     A'ANALYST.'//1H ,2X,'A.  FELLER-BUNCHERS.',10X ,I10,'  MACHINE(S)',
     B5X,'TRACKED TYPE')
C
    4 FORMAT(1H0,'II.  SYSTEM CHARACTERISTICS AS SPECIFIED BY THE ',
     A'ANALYST.'//1H ,2X,'A.  FELLER-BUNCHERS.',10X ,I10,'  MACHINE(S)',
     B5X,'RUBBER-TIRED TYPE',//)
C
C
    8 FORMAT(
     A /1H0,'  B.  SKIDDERS.',10X ,I10,'  MACHINE(S)',5X,'RUBBER',
     A'-TIRED GRAPPLE SKIDDER(S).  ',//)
C
    9 FORMAT(1H,8X,'MAXIMUM SKID BUNCH HAS TOTAL SUM OF '
     A'DIAMETER',F8.2,' INCHES'//)
C
   11 FORMAT(1H0,'  C.  CHIPPER-LOADER.',//1H,8X,'THE LOADER',
     A' CAN TAKE A LOAD OF ',F5.0,'TREES')
C
C
   13 FORMAT(1H,6X,'ENERGY BALANCE',//,12X,F6.2,' GAL/TON - ',
     A'FELLER BUNCHER',//,12X,F6.2,' GAL/TON - SKIDDER',//,
     B12X,F6.2,' GAL/TON - CHIPPER',//,11X,F7.2,' TOTAL GAL/TON ',
     C'@',F10.2,' BTU/GAL',///)
C
   14 FORMAT(1H,7X,F10.2,' BTU/TON USED AS FUEL',//,8X,F10.2,
     A' BTU/TON HARVESTED FROM WOOD',////,
     B9X,F9.2,5X,'ENERGY BENEFIT RATIO.')
C
      X1 = IX(1)
      X2 = IX(2)
      X3 = IX(3)
      X4 = IX(4)
      X5 = IX(5)
      I = I + 1
      IF ( I .GT. 6 ) I = 1
      GO TO (10,20,30,40,50,60),I
C
   10 CONTINUE
      AVVOL= X1/100.
C AVVOL = AVERAGE VOLUMN PER ACRE - CUFT.
      AVDBH= X2/100.
C AVDBH = AVERAGE DBH - INCHES
      AVHGT=X3
C AVHGT = AVERAGE TREE HEIGTH - FEET
      TRPAC= X4
C TRPAC = AVERAGE NUMBER TREES PER ACRE
      TRSPC=(43560./TRPAC)**.5
C TRSPC = AVERAGE TREE SPACING - FEET
      WRITE (6,1)
      WRITE(6,2)AVVOL,AVDBH,AVHGT,TRPAC,TRSPC
      RETURN
```

```
C
   20 CONTINUE
      NUMFB=X1
C NUMFB = NUMBER OF FELLER-BUNCHERS
      FBTYP=X2
C  FBTYP  FELLER BUNCHER TYPE  0 = DROTT  1 = RUBBER-TIRED TYPE
      IF(FBTYP.EQ.0)WRITE(6,3)NUMFB
      IF(FBTYP.EQ.1)WRITE(6,4)NUMFB
      RETURN
C
   30 CONTINUE
      MXSKD  = X1
C   MXSKD     MAXIMUM SUM OF DIAMETER PER BUNCH
      NUMSK=X2
C NUMSK = NUMBER OF SKIDDERS
      WRITE(6,8) NUMSK
      WRITE(6,9) MXSKD
      XLODLM = X3
C  CHIPPER LOAD LIMIT
      WRITE(6,11)XLODLM
      RETURN
C
   40 CONTINUE
      WBTU=X1
C  BTU PER TON OF WOOD
      XDEN=X2
C  LBS OF WOOD PER CU. FT.
      FBGPT = X3/100
      FBTU=X4
      RETURN
C
   50 CONTINUE
C  HOURS SKIDDER WORKED
      SKHR = X1/100.
      SKGPH = X2/100
C  SKIDDER FUEL CONSUMPTION - GAL/HOUR
      SKTNS = X3*XDEN/200000
C  SKIDDER PRODUCTION IN TONS
      RETURN
C
   60 CONTINUE
      CPHR = X1/100.
C  HOURS CHIPPER WORKED
      CPGPH = X2/100
C  CHIPPER FUEL CONSUMPTION - GAL/HOUR
      CPTNS = X3*XDEN/200000
C  CHIPPER PRODUCTION IN TONS
C  CALCULATE TOTAL FUEL CONSUMPTION
      SKTFC = SKHR * SKGPH
      CPTFC = CPHR * CPGPH
      SKGPT = SKTFC/SKTNS
      CPGPT = CPTFC/CPTNS
      TGPT = FBGPT+SKGPT+CPGPT
      TONS = SKTNS
C  TOTAL TONS COMPLETE
C  CHANGE TO CPIR TONS WHEN ADDED
      FBTFC = FBGPT*TONS
      SKTFC = SKGPT*TONS
      CPTFC = CPGPT*TONS
      TFC = FBTFC+SKTFC+CPTFC
C  CALCULATE GALLONS OF FUEL PER TON
C BTU PER TON USED AS FUEL
      BTUTF = TGPT * FBTU
C  ENERTY BENEDIT RATIO
      EBC = WBTU/BTUTF
C
C
      WRITE(6,13)FBGPT,SKGPT,CPGPT,TGPT
C
      WRITE(6,14)BTUTF,WBTU,EBC
      RETURN
      END
```

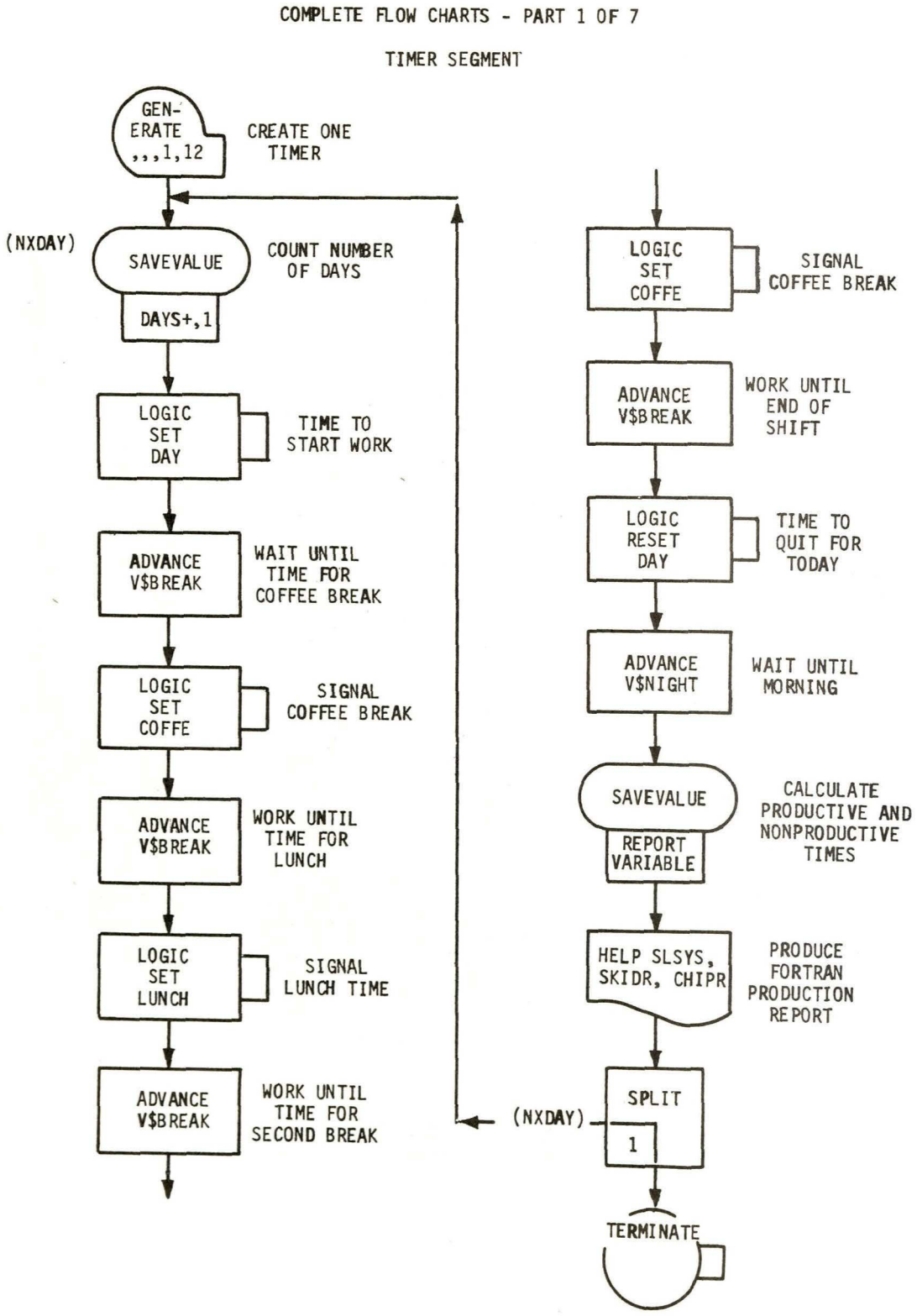
```
      SUBROUTINE SKIDR (IX)
      DIMENSION IX(5)
      DATA I/0/
      REAL   SKTNS
      INTEGER SKDIS,SKBUN,SKTRE
C
C
    1 FORMAT(1H1,9X,'S K I D D I N G   P R O D U C T I O N   A N D',
     A'   C O S T   S U M M A R Y '//////,1H,132('*'),//,1H,'II.   A.',
     BF8.2,5X,'HOURS WORKED BY SKIDDER(S).',//,1H,6X,'B.',I5,8X,
     C'NUMBER OF SKIDDER(S).',//
     D                          1H ,'II.   A.',I5,8X,'BUNCHES ',
     E'SKIDDED - ALL MACHINES.',/)
C
    2 FORMAT(1H,15X,F8.2,5X,'AVERAGE NUMBER OF FELLER-BUNCHER BUNCHES',
     A' COLLECTED.',//,16X,F8.2,5X,'AVERAGE NUMBER OF TREES PER',
     B' SKIDDER BUNCH.',//,
     C7X,'B.',I5,8X,'TREES SKIDDED - ALL MACHINES.',//,7X,'C.',
     DF8.2,5X,'VOLUME SKIDDED - CU.FT. - ALL MACHINES.',//,7X,'D.',
     E  I8,5X,'TOTAL DISTANCE SKIDDED.',//,7X,'E.',
     FF8.2,5X,'TOTAL TONS SKIDDED - ALL MACHINES.',///)
C
    3 FORMAT(1H,'III.  A.',F8.2,5X,'BUNCHES SKIDDED PER MACHINE ',
     A'HOUR.',//,7X,'B.',F8.2,5X,'TREES SKIDDED PER MACHINE HOUR.',///,
     B7X,'C.',F8.2,5X,'VOL. SKIDDED PER MACHINE HOUR. - CU.FT.',
     C//,7X,'D.',F8.2,5X,'TONS SKIDDED PER MACHINE HOUR.'/)
C
    4 FORMAT(1H,'IV.   A.',F8.2,5X,'AVERAGE ONE-WAY SKID DISTANCE ',
     A'PER TRIP - FEET.',//,7X,'B.',F8.2,5X,'AVERAGE ROUND TRIP ',
     B'TIME IN MINUTES - ALL ACTIVITIES.',//,      16X,F8.2,5X,
     C          'TIME - LANDING TO WOODS AND RETURN.',//,16X,
     DF8.2,5X,'PRODUCTIVE TIME - LANDING ACTIVITY.',//,
     F    16X,F8.2,5X,'NON-PRODUCTIVE TIME-WAITING TO DROP AT CHIPPER.',
     G  //1H ,15X,F8.2,5X,'TIME ON BREAKS'/)
C
C
    6 FORMAT(1H,'V.    A.',F8.2,5X,'TOTAL GALLONS USED.',//,16X,
     A   F8.2,5X,'GALLONS PER HOUR.',///,        16X,F8.2,5X,'GALLONS',
     B' PER TON.')
C
      X1 = IX(1)
      X2 = IX(2)
      X3 = IX(3)
      X4 = IX(4)
      X5 = IX(5)
C
      I = I+ 1
      IF (I .GT. 4) I = 1
      GO TO (10,20,30,40),I
C
   10 CONTINUE
      SKHR = X1/100.
      NUMSK = X2
C NUMSK = NUMBER OF SKIDDERS
      SKBUN = X3
C SKBUN = BUNCHES SKIDDED, ALL MACHINES
      SKTRE = X4
C SKTRE = TREES SKIDDED, ALL MACHINES
      RETURN
C
```

```
      20 CONTINUE
         SKVOL = X1/100.
C SKVOL = VOL. SKIDDED -CUFT. -ALL MACHINES
         BNTOT = X2
C  TOTAL NUMBER OF FELLER-BUNCHER BUNCHES.
         SKDIS = X3
C SKDIS = DISTANCE SKIDDED -FEET PER ROUND TRIP -ALL MACHINES
         BNAVE = BNTOT/SKBUN
C  BNAVE  THE AVE. # OF FELLER BUNCHER BUNCHES COLLECTED
         RETURN
C
      30 CONTINUE
         SKPWL = X1 /( 100.*SKBUN)
C SKPWL = PRODUCTIVE TIME - LANDING TO WOODS AND RETURN
         SKLND = X2/(100.*SKBUN)
         SKNLN = X3 /( 100.*SKBUN)
C SKNLN = NON-PRODUCTIVE TIME - WAITING TO DROP THE BUNCH AT THE CHIPPER
C SKBRK = TIME ON BREAKS
         SKBRK = X4/(100.*SKBUN)
         SKPLN = SKLND - SKNLN - SKBRK
         RETURN
C
      40 CONTINUE
         LBCFT = X1
C  LBCFT   POUNDS PER CUBIC FOOT OF WOOD
         SKGPH = X2/100
C  SKGPH   SKIDDER  GALLONS/HOUR
C
         SKTPB = SKTRE*1./SKBUN
C    SKTPB   TREES PER BUNCH
         WRITE(6,1)SKHR,NUMSK,SKBUN
C
         SKTNS = (SKVOL*LBCFT)/2000.
C    SKTNS   TOTAL TONS SKIDDED
         SKBMH = SKBUN/SKHR
C SKBMH = BUNCHES SKIDDED PER MACHINE HOUR
         SKTMH = SKTRE/SKHR
C SKTMH = TREES SKIDDED PER MACHINE HOUR
         WRITE(6,2)BNAVE,SKTPB,SKTRE,SKVOL,SKDIS,SKTNS
C
C
         SKVMH = SKVOL/SKHR
C SKVMH = VOL. SKIDDED PER MACHINE HOUR
         SKTNH = SKTNS/SKHR
C    SKTNH   TONS SKIDDED PER MACHINE HOUR
         SKADS = SKDIS*1./(2.*SKBUN)
C SKADS = AVERAGE ONE-WAY SKID DISTANCE PER TRIP - FEET
         SKTMA = SKHR*60/SKBUN
C SKTMA = AVERAGE ROUND TRIP TIME IN MINUTES - ALL ACTIVITIES
         WRITE(6,3)SKBMH,SKTMH,SKVMH,SKTNH
C
         WRITE(6,4)SKADS,SKTMA,SKPWL,SKPLN,SKNLN,SKBRK
C
C
C
         SKTGU = SKGPH*SKHR
C    SKTGU   TOTAL GALLONS USED
         SKGPT = SKTGU/SKTNS
C    SKGPT   GALLOMS PER TON
         WRITE(6,6)SKTGU,SKGPH,SKGPT
         RETURN
         END
```

```
      SUBROUTINE CHIPR (IX)
      DIMENSION IX(5)
      INTEGER       CPLOD
      INTEGER CPTRE,CPVNS
C
    1 FORMAT(1H1,9X,'C H I P P E R - L O A D E R   P R O D U C T ',
     A'I O N   A N D   C O S T   S U M M A R Y ',//,1H,132('*'),///
     B///,1H,'I.    A.',F8.2,5X,'HOURS WORKED BY CHIPPER-LOADER.',
     C       ///,1H,'II.   A.',I5,8X,'LOADS CHIPPED.',//,1H,
     E     15X,F8.2,5X,'AVERAGE NUMBER OF STEMS PER LOAD.',//,1H,
     F 15X,F8.2,5X,'AVERAGE VOLUME PER LOAD - CU.FT.',/)
C
    2 FORMAT(1H,    6X,'B.',I8,5X,'TREES CHIPPED.',//,7X,'C.',F8.2,
     A5X,'VOLUME CHIPPED - CU.FT.',//,7X,'D.',F8.2,5X,'TONS CHIP',
     B'PED.',//,7X,'E.',I8,5X,'VANS FILLED.',///,     16X,F8.2,5X,
     C'AVERAGE NUMBER OF LOADS PER VAN.',///,     16X,F8.2,5X,
     D'AVERAGE VOLUME PER VAN - CU.FT.',///,     16X,F8.2,5X,
     E'AVERAGE TONS PER VAN.',///)
C
    3 FORMAT(1H,'III.   A.',F8.2,5X,'LOADS CHIPPED PER MACHINE HOUR.',
     A//,7X,'B.',F8.2,5X,'TREES CHIPPED PER MACHINE HOUR.',//,7X,
     B'C.',F8.2,5X,'VOLUME CHIPPED PER MACHINE HOUR - CU.FT.',//,
     C7X,'D.',F8.2,5X,'TONS CHIPPED PER MACHINE HOUR.',//,
     D7X,'E.',F8.2,5X,'VANS FILLED PER MACHINE HOUR.',///)
C
    4 FORMAT(1H,'IV.    A.',F8.2,5X,'AVERAGE CHIPPING TIME PER VAN',
     A' FILLED - ALL ACTIVITIES - MINUTES.',//,       16X,F8.2,5X,
     B'PRODUCTIVE TIME PER VAN - MINUTES.',//,     16X,F8.2,5X,
     C'NON-PRODUCTIVE TIME PER VAN - DUE TO EXTERNAL EVENTS - MIN',
     D'UTES.',//,          23X,F8.2,5X,'LOADER WAITING FOR WOOD FROM',
     E' SKIDDERS - MINUTES.',//,          23X,F8.2,5X,'CHIPPER WAIT',
     F'ING FOR VANS TO FILL - MINUTES.',//1H ,22X,F8.2,5X,
     G  'BUCKING TIME'//1H ,22X,F8.2,5X,'BREAK TIME'///)
C
C
    6 FORMAT(1H,'VI.    A.',F8.2,5X,'TOTAL GALLONS OF FUEL USED.',
     A//,     16X,F8.2,5X,'GALLONS/HOUR.',//,       16X,F8.2,
     B5X,'GALLONS/TON.')
C
       X1 = IX(1)
       X2 = IX(2)
       X3 = IX(3)
       X4 = IX(4)
       X5 = IX(5)
C
      I = I+ 1
      IF ( I .GT. 3 ) I = 1
      GO TO ( 10,20,30 ) , I
C
   10 CONTINUE
      CPHR = X1/100.
      LBCFT = X2
C    LBCFT   POUNDS OF WOOD PER CUBIC FOOT
      CNPWD = X3/100.
C CNPWD = LOADER WAITING FOR WOOD FROM SKIDDER
      CNPVN = X4/100.
C CNPVN   = CHIPPER WIATING FOR VAN FROM TRUCKS
      CPGPH = X5/100.
C    CPGPH    CHIPPER-LOADER GALLONS PER HOUR
      RETURN
```

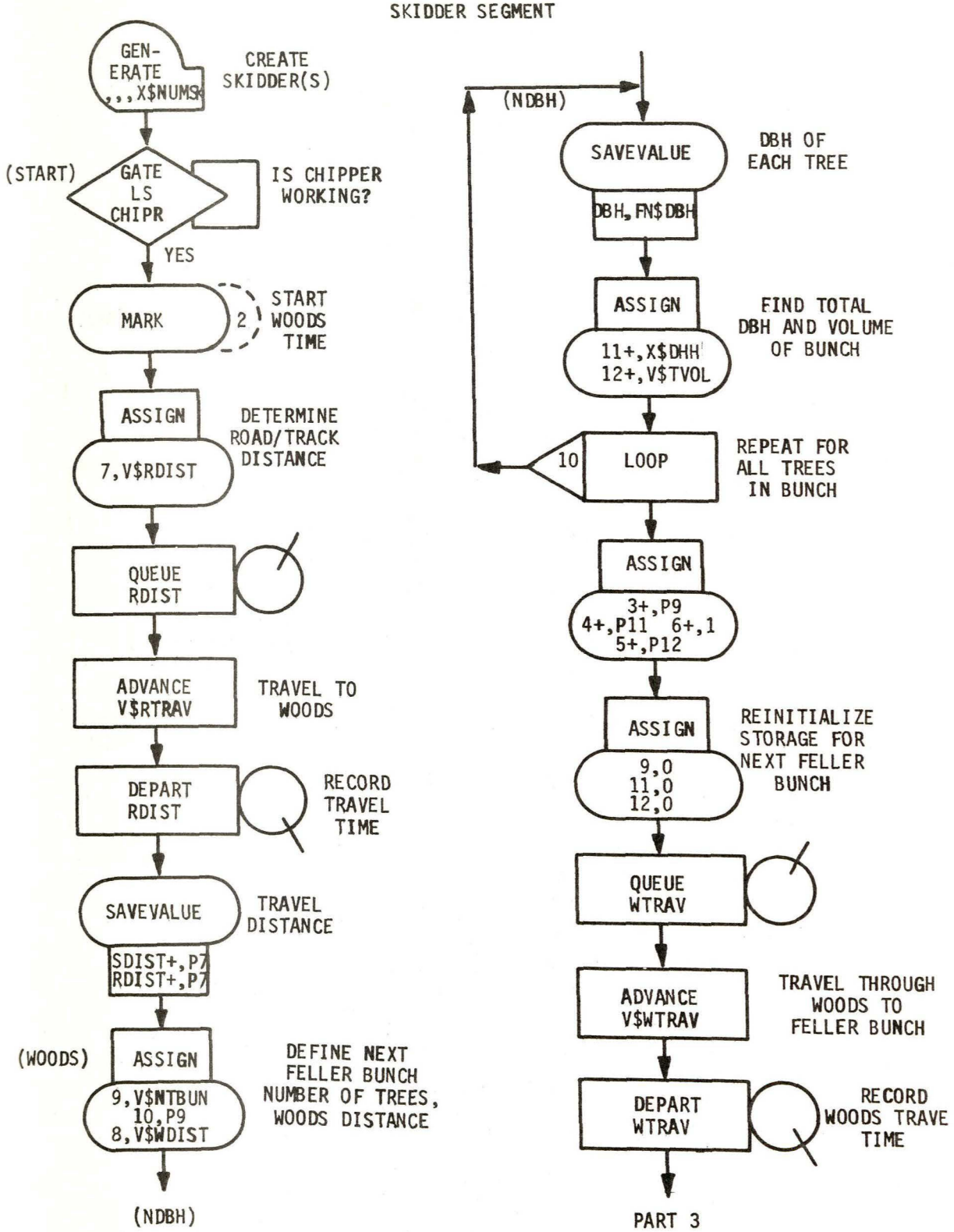
```
C
   20 CONTINUE
      CPTRE = X1
C CPTRE = TREES CHIPPED
      CPVOL = X2/100.
C CPVOL = VOLUME CHIPPED, CUFT.
      CPVNS = X3
C CPVNS = VANS FILLED
      CPLOD = X4
C CPLOD = LOADS CHIPPED
      BUCK = X5/100
C BUCK = BUCKING TIME
      RETURN
C
   30 CONTINUE
      CPBRK = X1/100
C CPBRK = BREAK TIME
C
      CPSPL = CPTRE*1./CPLOD
C CPSPL = AVERAGE NUMBER OF STEMS PER LOAD
      CPVPL = CPVOL/CPLOD
C CPVPL = AVERAGE VOLUME PER LOAD, CUFT.
      WRITE (6,1)                CPHR,          CPLOD,CPSPL,CPVPL
      CPTNS = (CPVOL*LBCFT)/2000.
C   CPTNS   TOTAL TONS CHIPPED
C
      CPLPV = CPLOD*1./CPVNS
C CPLPV = AVERAGE NUMBER OF LOADS PER VAN
      CPVPV = CPVOL/CPVNS
C CPVPV = AVERAGE VOLUME PER VAN, CUFT.
      CPTPV = CPTNS/CPVNS
C   CPTPV   TONS PER VAN
      WRITE(6,2)CPTRE,CPVOL,CPTNS,CPVNS,CPLPV,CPVPV,CPTPV
C
      CPLMH = CPLOD/CPHR
C CPLMH = LOADS CHIPPED PER MACHINE HOUR
      CPTMH = CPTRE/CPHR
C CPTMH = TREES CHIPPED PER MACHINE HOUR
      CPVLH = CPVOL/CPHR
C CPVLH = VOLUME CHIPPED PER MACHINE HOUR, CUFT.
      CPVNH = CPVNS/CPHR
C CPVNH = VANS FILLED PER MACHINE HOUR
      CPTNH = CPTNS/CPHR
C   CPTNH   TONS CHIPPED PER MACHINE HOUR
      CPACT = CPHR *60/CPVNS
C CPACT = AVERAGE CHIPPING TIME PER VAN FILLED - ALL ACTIVITIES -MINUTES
      WRITE(6,3)CPLMH,CPTMH,CPVLH,CPTNH,CPVNH
C
      CPNPT =(CNPWD + CNPVN + BUCK + CPBRK)/CPVNS
C CPNPT = NON PRODUCTIVE CHIPPERN TIME
      CPPTM = CPACT-CPNPT
C CPPTM = PRODUCTIVE TIME PER VAN - MINUTES
      CNPWD = CNPWD/CPVNS
      CNPVN  = CNPVN/CPVNS
      BUCK = BUCK/CPVNS
      CPBRK = CPBRK/CPVNS
      WRITE(6,4)CPACT,CPPTM,CPNPT,CNPWD,CNPVN,BUCK,CPBRK
C
C
      CPTGU = CPHR*CPGPH
C   CPTGU   TOTAL GALLONS USED
      CPGPT = CPGPH/CPTNH
C   CPGPT   GALLONS PER TON
      WRITE(6,6)CPTGU,CPGPH,CPGPT
      RETURN
      END
```

APPENDIX C
COMPLETE FLOW CHARTS



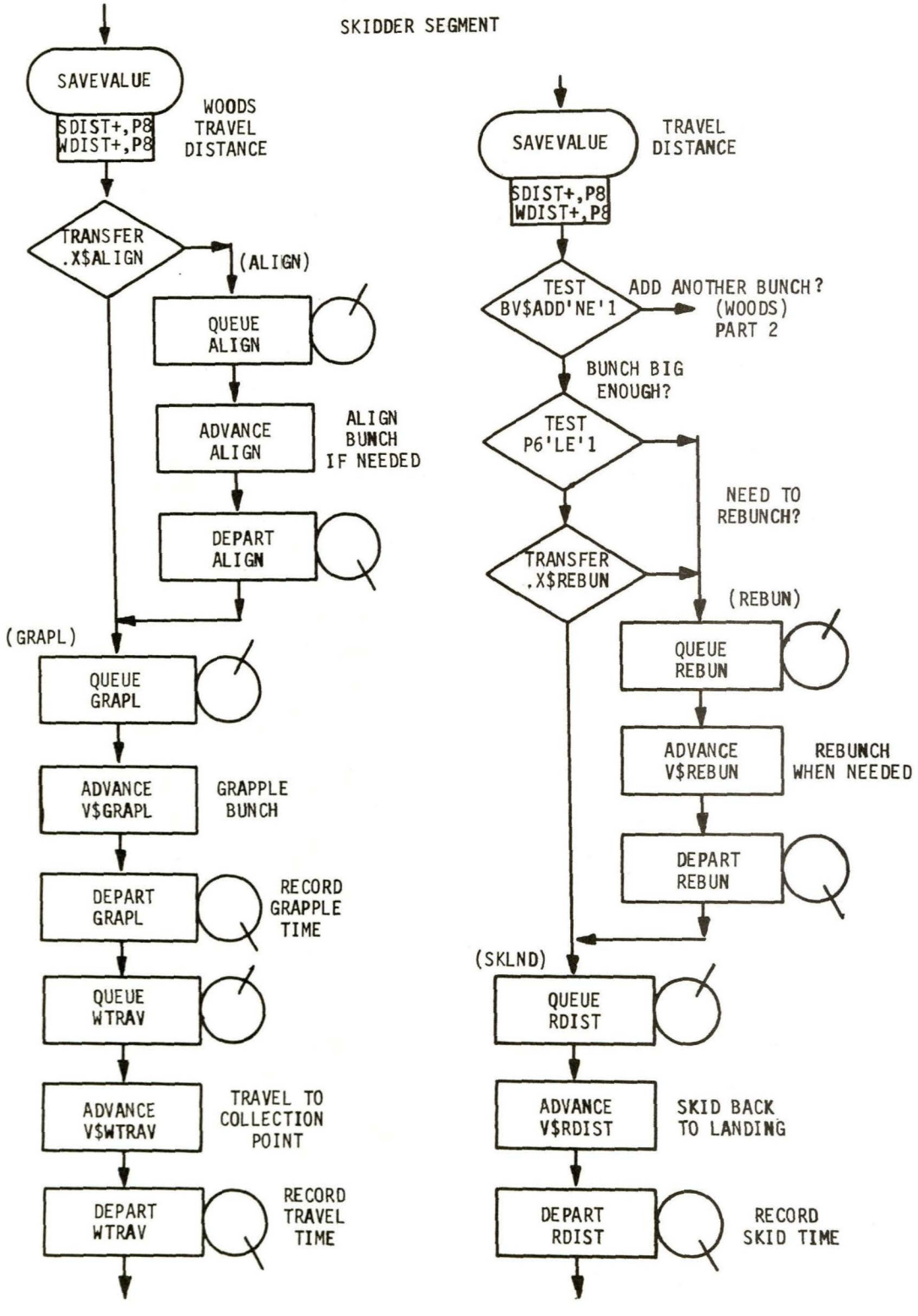
COMPLETE FLOW CHARTS - PART 2 OF 7

SKIDDER SEGMENT



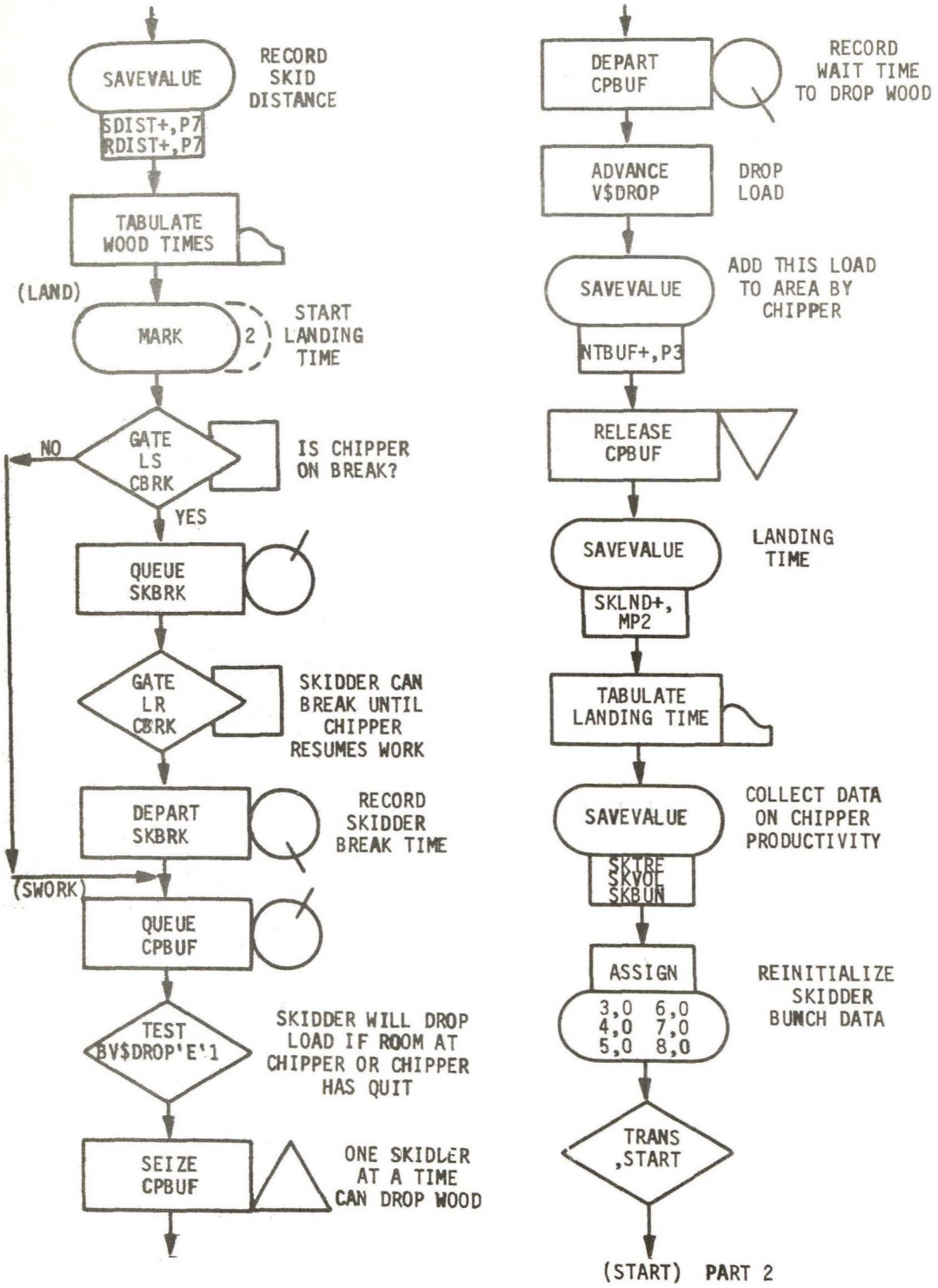
COMPLETE FLOW CHARTS - PART 3 OF 7

SKIDDER SEGMENT



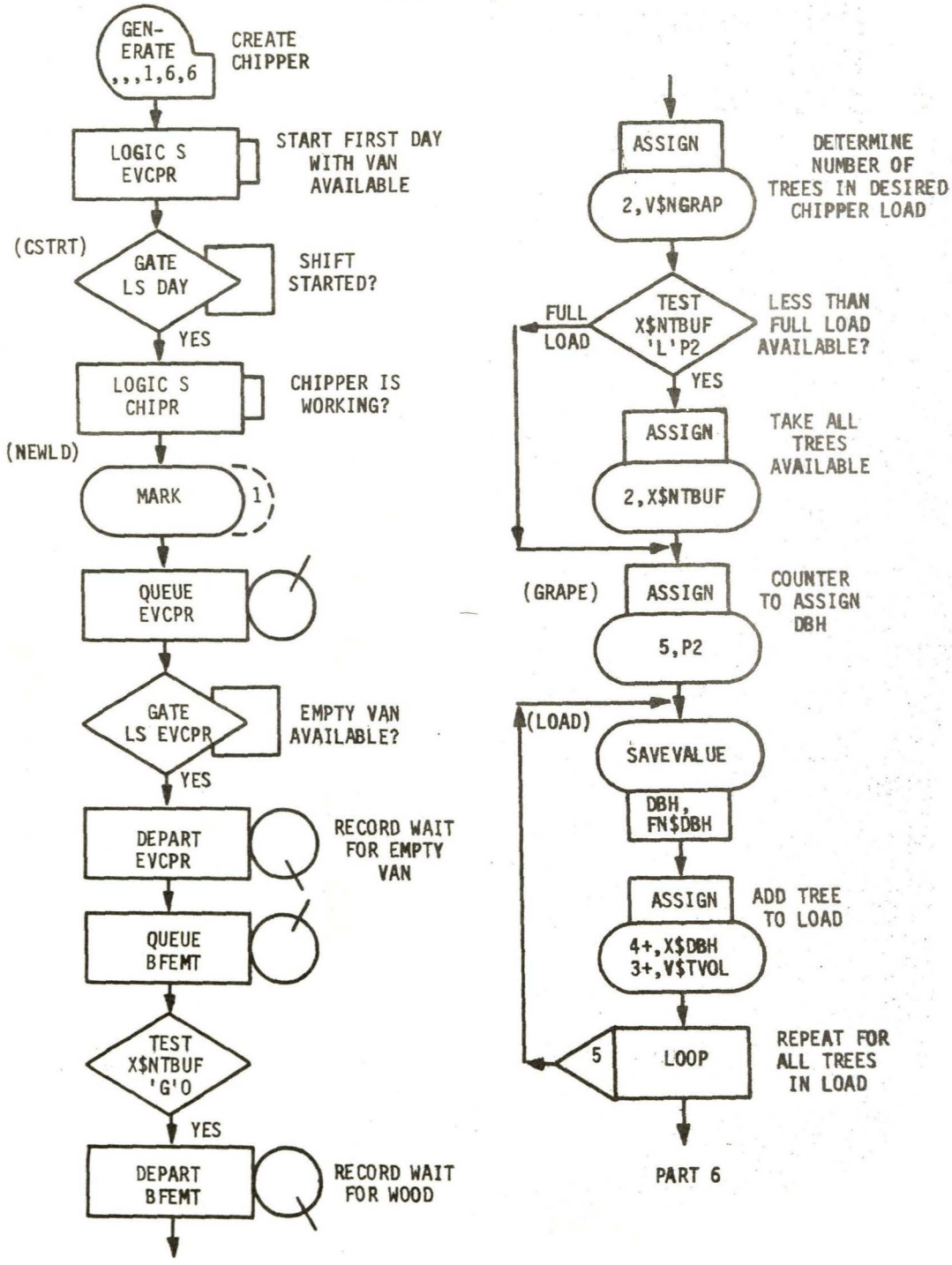
COMPOETE FLOW CHARTS - PART 4 OF 7

SKIDDER SEGMENT



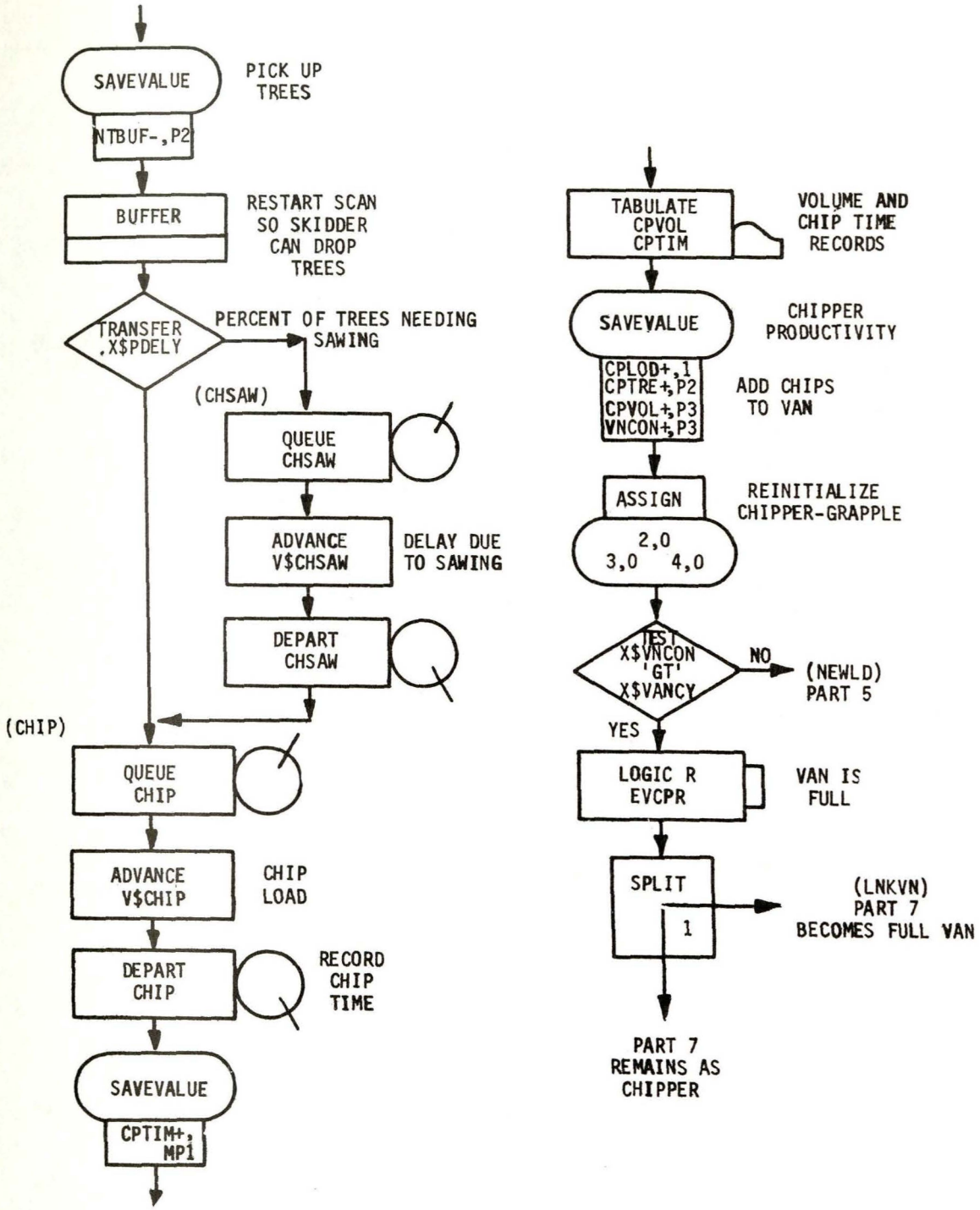
COMPLETE FLOW CHARTS - PART 5 OF 7

CHIPPER SEGMENT



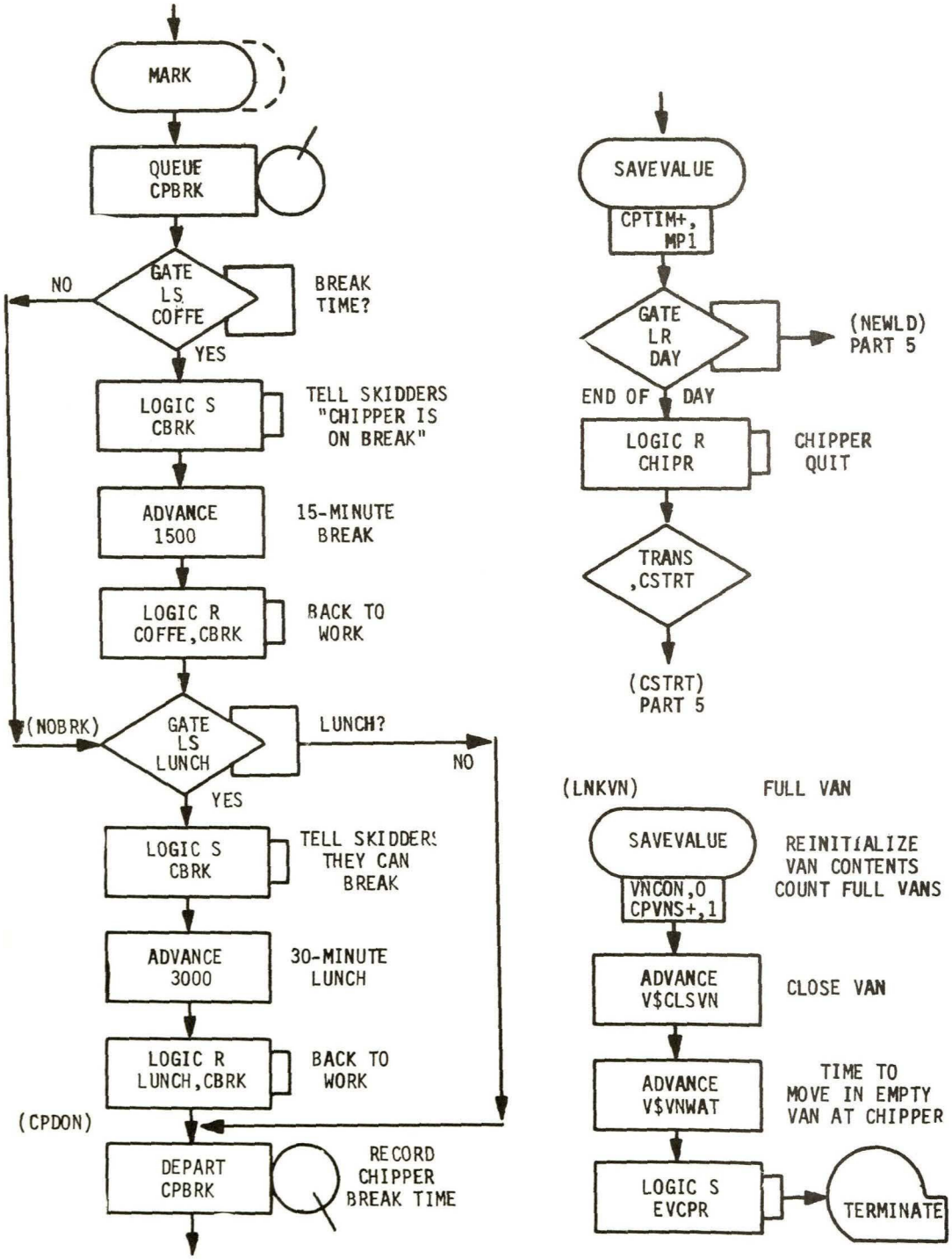
COMPLETE FLOW CHARTS - PART 6 OF 7

CHIPPER SEGMENT



COMPLETE FLOW CHARTS - PART 7 OF 7

CHIPPER SEGMENT



☆U.S. GOVERNMENT PRINTING OFFICE: 1982—566-950/99

Winsauer, Sharon A.

A program and documentation for simulation of grapple skidders and a whole-tree chipper. Res. Pap. NC-221. St. Paul, MN: U.S. Department of Agriculture, Forest Service, North Central Forest Experiment Station; 1982. 42 p.

Presents a computer model written in GPSS (General Purpose Simulation System) designed to simulate a skidding-chipping operation.

KEY WORDS: GPSS (General Purpose Simulation System), computer, harvesting, productivity, modeling.